

THE ROLE OF RELATIVE PHYSICAL AND  
SUBJECTIVE INTENSITIES IN THE BACKWARD  
INTERFERENCE PITCH RECOGNITION PARADIGM

By  
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THE ROLE OF RELATIVE PHYSICAL AND  
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Five experiments are described which investigated the importance of, and the relationship between, relative physical and subjective stimulus intensities in the perception of the pitch of a brief auditory signal that is temporally adjacent to a successive, longer duration interfering stimulus. Using the single interval, backward interference pitch recognition paradigm, a supra-threshold, 20-msec sinusoid was followed closely in time (5 msec) by a 500-msec, sinusoidal interfering tone of 70 dB (SPL) intensity.

Experiment I confirmed the hypothesis that pitch discriminability improves as the physical intensity of the 20-msec signal increases relative to the intensity of the interfering tone. Experiment II showed

that this pitch discriminability improvement is due to relative physical intensities and not simply to a changing absolute signal intensity. Experiments III and IV tested the assumption of Massaro's cognitive-perceptual pitch recognition model regarding the equality of the subjective intensities of the signal and interfering tone. The results of these two experiments indicated that, in fact, the two stimuli are not equal in subjective intensity and that the extent of this inequality varies for individual listeners. An additional finding of Experiment IV suggested that the perception of pitch and the perception of subjective intensity are not orthogonal, but rather that judgments regarding one dimension co-vary with decisions regarding the other dimension. Furthermore, the accuracy of a particular pitch judgment was found to be more highly correlated with subjective signal intensity than with physical intensity. Experiment V was designed as a pilot study of the potential importance of a physical variable, stimulus rise-decay time, in the determination of subjective stimulus intensity. This investigation found that rise-decay time differences as small as 3 msec can result in subjective intensity differences as large as 6.3 dB in brief duration stimuli.

The implications of the preceding findings to existing theories and for future research are discussed.

## CHAPTER I

### INTRODUCTION

The frequency resolution of a brief auditory stimulus that is temporally proximal to a second, interfering stimulus has become a topic of increasing popularity among investigators in recent years. The relevance of this question to a variety of common auditory experiences is indubitable and is illustrated by the following examples. The minuets of Haydn, Mozart, Schubert, etc. contain series of temporally adjacent sixteenth notes, each of 100 msec duration or less. These, as well as the occasional and even briefer thirty-second notes, undoubtedly contribute to the beauty of these works, yet researchers are not presently able to describe positively the physical parameters which govern the perception of these stimuli. Similarly, the perception of short-duration consonants and vowels which occur in close succession during speech remains an active area of research.

Because of the pertinence of this question to common auditory experiences, investigators have employed a number of different stimuli in their attempts to discover the process by which we are able to assign meaning to very brief acoustical stimuli. For example, research has been completed using relatively complex speech sounds (e.g., Darwin, 1971; Wolf, 1976), as well as tones corresponding to musical notes (e.g., Dowling, 1971, 1973a, 1973b; Elliot, 1971; Idson & Massaro, 1976). The majority of investigators, however, have chosen to employ pure tones.

All of these studies, even though often employing different methods and stimuli, have generally found that the pitch perception of a brief acoustical signal is degraded when it is followed closely in time by a second auditory stimulus. Because most of the research in this area has utilized pure tones as the signals of interest, further discussion in this introduction will be limited to these studies.

Figure 1 diagrammatically describes a generalized sequence of events that constitutes a trial in experiments of this sort.

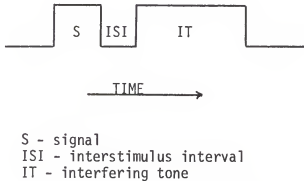


Figure 1. Generalized Temporal Relationship of Signal and Interfering Tone.

The task of the subject is typically to make some judgment regarding the pitch of the signal.

The variables that have been manipulated in attempts to understand the process of the pitch perception of a brief (about 20 msec) pure tone that is potentially degraded by a successive, longer duration (usually 300-500 msec) sinusoid include: the frequency relationship of the signal and interfering tone, the duration of the interstimulus interval, the duration of the interfering tone, the sophistication of the subjects, the amount of signal uncertainty associated with each

trial, and differential performances resulting from paradigmatic variations. Because of the widespread interest in this question, investigators of differing orientations have employed functionally different methods, which, at times, have yielded incompatible results. Consequently, consensual conclusions and parametric constants have been difficult to derive. Therefore, to facilitate an understanding of research in this area, as well as to foster an appreciation of the methods chosen for the present studies, the literature regarding the variables that are potentially operative in this pitch perception question is reviewed in a portion of this chapter.

The primary purpose of this investigation, however, is to explore the possible effects of a hitherto overlooked variable--relative intensity. Among the questions that will be addressed include the following:

1. Is the pitch perception of the brief auditory signal affected by relative intensity differences between the signal and interfering tone?
2. If a difference in performance is obtained, is it due, in fact, to the relative intensities of the signal and interfering tone or simply to a changing signal intensity?

Answers to these questions will be sought in Experiments I and II.

A second class of questions (Experiments III and IV) stems, in part, from the development of a cognitive-perceptual model (Massaro, 1972a) designed to explain the process of brief signal pitch perception. A fundamental assumption of this model is that the subjective intensities (i.e., loudness) of the signal and interfering tone are equal. Extant research in the area of subjective intensity suggests that, in fact, the

two tones may not be equally loud. Therefore, the present investigation will attempt to answer the following additional questions:

3. When the signal and interfering tone are of equal physical intensities, does the subject perceive them to be of equal subjective intensity?
4. If not, what is the point of subjective equality?

Finally, in an attempt to further reconcile inter-investigation differences, a preliminary examination of the effect of a potentially critical variable and its relation to subjective intensity will be undertaken. Experiment V will attempt to provide a preliminary answer to the following question:

5. What is the effect of rise-decay time on the subjective intensity of the signal?

The five experiments designed to answer the aforementioned questions will be preceded by a brief description of the paradigm to be employed and a general review of the experimental findings regarding the variables that have been deemed important in the process of the pitch perception of a potentially degraded, short duration acoustical stimulus.

### Review of Relevant Literature

#### Basic Paradigm

While differences across studies exist, there are several procedural characteristics which the majority of the investigations in this area share. First, the duration of the signal ranges from 10 to 40 msec, with 20 msec being modal. Secondly, the subsequent interfering tone does not overlap the signal in time and the interval between these stimuli

is typically varied from 0 to 250 msec. The interfering tone, relative to the signal, is generally of longer duration, but of equal physical intensity and complexity. Finally, the task of the subject involves decisions regarding the frequency characteristics of the signal. These responses may take the form of absolute identifications (e.g., consonant names), relative identifications (e.g., high vs. low in pitch), or simply discriminative judgments (e.g., same or different in pitch). A tabulation of the methodological and parametric differences between studies is summarized in Table 1.

A number of potentially critical variables have received the attention of researchers of this problem and a brief review of their findings follows.

#### Frequency Relationship of Signal and Interfering Tone

Employing a paradigm which has come to be known as the "backward recognition masking" procedure, Massaro (1970) presented subjects one of two equiprobable, 20-msec signals (770 or 870 Hz) followed 0 to 500 msec later by a 500-msec "masker" (820 or 999 Hz). Subjects were required to report whether the signal had been "high" or "low" in pitch. He found that at interstimulus intervals of less than 80 msec, the 999 Hz interfering tone produced significantly more interference than the 820 Hz tone. However, when interfering tone frequency values were varied randomly within a block of trials, this difference disappeared. (This random presentation of critical variable values within trial blocks is characteristic of most experiments by Massaro. In this instance, signal frequency, interstimulus interval, interference tone frequency, and the

Table 1. Paradigms and Critical Variable Values Employed by Selected Investigators.

| Investigator/s                | Paradigm  | Signal Duration (msec) | ISI (msec)    | Intrfrg Tone (msec) | Subject Practice    | Trial Uncertainty              |
|-------------------------------|---|------------------------|---------------|---------------------|---------------------|--------------------------------|
| Hawkins et al. (1974)         | single-interval   | 20                     | 0, 250        | 500                 | 80 trls             | 2 (pitch)                      |
| Holding, Loeb, & Yoder (1972) | same-different  | 20, 300                | 40            | 450                 | 40 trls             | 2 (pitch)                      |
| Leshowitz & Cudahy (1973)     | 2-altrntv forced choice                                     | 10, 20                 | 20-160        | 500                 | "20-66 hrs"         | 2 (pitch)                      |
| Loeb & Holding (1975)         | single-interval   | 20                     | 40            | 500                 | "continuous"        | 2 (pitch)                      |
| Massaro (1970)                | single-interval   | 20                     | 0-500         | 500                 | "15 hrs"            | 16 random conditions           |
| Massaro (1971)                | single-interval   | 20                     | 0-500         | 50, 100, 200, 400   | 1200 trls           | 64 possible conditions         |
| Massaro (1972b)               | single-interval   | 20-440                 | 30-430        | 80, 240             | 600 trls            | 32 random conditions           |
| Massaro (1975)                | sngl-intvl, 2-altrntv frcd chce, same-different             | 20                     | 10-240, 0-240 | 500                 | 3200, 600, 600 trls | 2 (pitch), 8 random conditions |
| Yost, Berg, & Thomas (1976)   | sngl-intvl, 2-altrntv frcd chce, same-different, adjustment | 20                     | 5, 100        | 500                 | more than 2500 trls | 2 (pitch)                      |

ear to which the signal was presented were uncertain on each trial.) Massaro concluded that the frequency relationship of the signal and interference tone is an insignificant determinant of the amount of "masking" occurring with this paradigm. It should be noted that this finding is contrary to the critical bandwidth data that have accrued as a result of detection (signal presence or absence) masking studies which indicate that the amount of masking is a function of signal-masker similarity (e.g., Elliot, 1967; Fletcher, 1940).

Hawkins, Thomas, Presson, Cozic, and Brookmire (1974), utilizing the same backward recognition masking paradigm and similar stimuli, found that differential interference effects occurred as a function of signal-interfering tone similarity and that the nature of this interaction depended upon the uncertainty associated with each trial.

On the other hand, Loeb and Holding (1975) found no difference between the interfering effects of 820 and 1689 Hz on signals of 770 or 870 Hz. Similarly, Leshowitz and Cudahy (1973) obtained minimal interference effects as a function of signal-interfering tone frequency similarity.

Watson, Wroton, Kelly, and Benbasset (1975) did find frequency dependent effects using a design comparable to the backward recognition masking paradigm. They found that higher frequency 40 msec components of 10-tone sequences were discriminated more readily than the lower frequency elements. Most recently, Massaro (1975) and Idson and Massaro (1976) concluded that the amount of interference is reduced when the interfering stimulus lies outside the octave band of the signal stimulus.

The question of the amount of backward interference that results

as a function of signal-interference tone frequency similarity has not been unequivocally answered. It has not been of foremost concern in backward interference studies and is typically confounded by procedural effects. The interval between the signal and interference tone, however, has been of active concern in the backward recognition interference literature.

### Interstimulus Interval

The interstimulus interval at which the perception of the signal stimulus is no longer affected by the interference stimulus has been variously estimated to be from 20 msec (Lesowitz & Cudahy, 1973) to 250 msec (Massaro, 1970, 1972b, 1975).

Since the duration of the signal is usually about 20 msec, the persistence of an "echoic image" after stimulus offset is implied. Massaro (1970) has postulated the existence of a "preperceptual acoustic store" which serves to maintain a functionally identical representation of the signal after its offset and until it makes contact with a higher level memory which assigns it meaning. The time required for this identification process is approximately 250 msec (for tones). Any stimulus occurring prior to the completion of the identification of the signal effectively "writes over" the image and terminates its processing. While the time course of "echoic memory" has been estimated to be as long as four secs (Treisman, 1964), studies suggesting durations longer than 250 msec have typically involved the recall of the stimulus and not simply its identification. Investigations involving the discrimination or identification of a signal that is being followed by an

interfering stimulus have indicated that the resolution of the frequency of that signal is completed in less than 250 msec.

Watson et al. (1975) introduced temporal gaps in their 10-tone sequences and found performance reaching an asymptote at intervals of 80 msec or longer. Their task involved the identification of a comparison sequence as being the same or different from a standard sequence along any of the 10 serial positions.

Yost, Berg, and Thomas (1976), utilizing the backward recognition masking paradigm, found little interference at intervals of 100 msec. Furthermore, Leshowitz and Cudahy (1973) obtained results indicating that a decrement in discriminability occurred only at intervals less than 20 msec (with a signal of 20 msec duration). Finally, Loebe and Holding (1975) discovered that highly practiced subjects required about 40 msec to resolve the frequency of the signal stimulus.

There is, therefore, somewhat less than a consensus regarding the time necessary for a subject to make a decision on the pitch characteristics of a brief auditory stimulus when it is followed closely in time by another auditory stimulus. This disparity of opinion can be attributed to task complexity, subject sophistication, and other procedural and paradigmatic differences.

#### Sophistication of the Subject

The degree of subject sophistication is a variable which has possibly been instrumental in contributing to incongruent conclusions regarding certain critical variables (e.g., interstimulus interval).

Massaro's subjects have usually been practiced less than those of

other studies. For example, Massaro (1970) presented 600 practice trials before test data were collected. In contrast, Ronken's (1972) subjects received 9,000 practice trials; Watson et al. (1975) trained subjects for "several hours" (in excess of 20); and Yost et al. (1976) trained subjects a minimum of 2500 trials before performance scores were recorded. In fact, Loeb and Holding (1975) showed a distinct practice effect through the first 1700-2000 trials, at which point discriminability reached an asymptote. Massaro (1975), in answer to this finding, employed subjects, who, after having received 3200 trials of practice, produced data replicating the 250 msec time course of the interstimulus interval. An examination of these data, however, reveals that performance reaches a virtual asymptote at an interstimulus interval of 120 msec. It appears, therefore, that stable subject performance in backward recognition interference tasks requires relatively highly practiced subjects.

### Degree of Uncertainty

As might be expected in a task of perceptual processing, the amount of uncertainty associated with the occurrence of the signal does contribute to the performance of a given subject. As noted earlier, subjects serving in experiments by Massaro are typically in a state of high uncertainty regarding not only the frequency of the signal, but also the locus of its occurrence and the interval between the signal and the interfering tone.

A look at subject performances across studies that vary in task uncertainty reveals far superior discriminability when uncertainty is

minimal. For example, Massaro's (1970) subjects were performing near chance levels at a signal frequency difference of 100 Hz (interstimulus interval of 20 msec) when uncertainty was very high. In contrast, Yost et al. (1976) using an identical paradigm, reported differences of 50 Hz to be sufficient to generate performances of 75% correct at an interstimulus interval of 5 msec. Similarly, Leshowitz and Cudahy (1973) reported a frequency difference of 15 Hz to be necessary for 75% performance levels. The Yost et al. and Leshowitz and Cudahy examples manipulated critical variables in a blocked fashion, although the differences in subject sophistication preclude the drawing of an unequivocal conclusion.

Hawkins et al. (1974) manipulated the uncertainty variable while holding subject sophistication constant. When the signal was always presented to the same ear and when interstimulus intervals and interfering stimulus frequency values were presented in a blocked manner, there was a significant improvement in performance, relative to that condition where interstimulus intervals and interfering tone frequencies were varied randomly trial by trial. Watson (1975) has also indicated that performances in frequency discrimination tasks vary inversely with task uncertainty.

#### Paradigm Differences

The three most popular paradigms that have been used in the investigations of the question of the frequency resolution of brief auditory stimuli followed by an interference stimulus are the single-interval, the two-alternative forced choice, and the same-different procedures. The single-interval paradigm involves the presentation of one of two

possible signals followed by a second, interfering stimulus. The subject's task is to indicate whether the signal that occurred was the "high" or "low" frequency alternative. The studies which have employed this paradigm include Hawkins et al. (1974), Loeb and Holding (1975), Massaro (1970, 1971, 1972b, 1975), and Yost et al. (1976).

The two-alternative forced choice (2AFC) procedure involves the presentation on each trial of one signal followed by the interfering stimulus, then the other possible signal followed by the interfering tone. The subject's task is typically to report whether the "high" signal occurred first or second or to report the sequence of signal occurrence, i.e., "high-low" or "low-high." Investigators utilizing this procedure include Leshowitz and Cudahy (1973), Massaro (1975), Ronken (1972), and Yost et al. (1976).

The third paradigm, the same-different procedure, generally involves the presentation of two signals or sequences of signals, e.g., Watson et al. (1975) that are each followed by the interfering tone. The subject indicates whether the two signals were the "same" or "different." This paradigm has been used by Elliot (1967), Holding, Loeb, and Yoder (1972), and Yost et al. (1976).

A fourth procedure, the method of adjustment, has been employed by Watson (1975) and Yost et al. (1976) to investigate the uncertainty variable. With this method, the subject adjusts a variable stimulus (in the presence of an interfering tone) to match a previously presented standard stimulus.

The question of the importance of paradigm selection in the investigation of backward auditory interference was answered by the Yost et al.

(1976) investigation. Comparing the three most popular paradigms, as well as the method of adjustment, these investigators, using comparably practiced subjects under conditions of high task certainty, found that the greatest interfering effects occurred with the single-interval procedure. The 2AFC and same-different methods resulted in much reduced effects which were not significantly different from performance in the absence of an interfering stimulus. The method of adjustment produced no interfering effects whatsoever. Furthermore, the greatest effect occurred with the single-interval paradigm at an interstimulus interval of 5 msec. An interstimulus interval of 100 msec produced performances that were indistinguishable from an interference-free condition.

#### Duration of the Interfering Stimulus

This variable is one of the few associated with the general question of the pitch perception of a brief auditory stimulus which has not been a subject of controversy.

Massaro (1971) systematically decreased the duration of the interfering stimulus from 500 msec to 20 msec and found no change in the amount of interference caused by the trailing stimulus. The fact that interfering effects can be exhibited across studies employing interfering stimuli of different durations suggests that this variable may not be of critical importance. The durations which have resulted in the interference of the signal stimulus include 40 msec (Ronken, 1972; Watson et al., 1975), 400 msec (Elliot, 1967), 450 msec (Holding, Loeb, & Yoder, 1972), and 500 msec (Hawkins et al., 1974; Leshowitz & Cudahy, 1973; Loeb & Holding, 1975; Massaro, 1970, 1971, 1972b, 1975; Yost et al., 1976).

The finding that interference tone duration is not of critical importance in pitch identification has its counterpart in detection masking research. Elliot (1971) reached a similar conclusion, although Penner (1974) and Penner, Cudahy, and Jenkins (1974) suggested that while masker duration is unimportant at interstimulus intervals of .1 msec and 100 msec, the duration of the masker may assume greater influence at intermediate intervals (3 msec). The signals in these studies were auditory clicks (100 microsecs), masked by Gaussian noise; masked thresholds were performance indices, not frequency discrimination scores.

### Discussion

This decrement in the ability to perceive correctly the pitch of a brief-duration auditory tone when it is closely followed by an interfering stimulus has been shown to be a function of a number of factors. The temporal proximity of the two stimuli is of critical importance, with estimates of the effective duration of the interstimulus interval ranging from 20 msec (Leshowitz & Cudahy, 1973) to 250 msec (Massaro, 1970, 1972b, 1975) and is probably responsible for a portion of the subject variability that exists across studies.

Also related to between-studies variance is task difficulty. Uncertain trial occurrence effectively precludes the development of any type of listening strategy or perceptual expectancy and results obtained under these conditions do not reflect optimal processing.

Finally, the psychophysical paradigm chosen will determine the degree to which the backward interference effect will be obtained (Yost et al., 1976). The paradigm which has consistently resulted in interference effects across levels of subject sophistication and task

uncertainty is the single-interval procedure. All studies employing this paradigm reported performance decrements at intervals less than 40 msec.

In light of the preceding findings, the following procedural constraints were adopted for use in all of the experiments described in this paper:

Paradigm. The single-interval paradigm was chosen because of its consistency in yielding interference effects.

Interstimulus interval. An interstimulus interval of 5 msec was employed throughout for similar reasons of interference consistency.

Subject sophistication. Because stable subject performance was desirable, test data were collected only after a minimum of 2500 practice trials was completed.

Task uncertainty. To help ensure optimal processing of the auditory signals, variables were manipulated in a blocked manner.

Frequency relationship of signal and interfering stimulus. The interfering stimulus was held constant at 800 Hz across studies, with the two possible signals always symmetrical about the interfering tone. For example, if the frequency difference ( $\Delta f$ ) between the "high" and "low" pitch alternatives were equal to 100 Hz, the two signals would be 850 Hz and 750 Hz, respectively.

Duration of stimuli. All of the experiments described in this paper utilized a signal duration of 20 msec and an interfering tone duration of 500 msec.

The five experiments described in the following chapters investigate the potential importance of relative physical and subjective stimulus intensities in the accurate perception of the pitch of a brief aural signal. The results of these experiments are relevant not only

to questions surrounding the frequency resolution of brief auditory stimuli, but also to factors involved in the subjective experience of stimulus loudness. In addition, the studies described in this paper will serve as a test of a fundamental assumption of a currently popular cognitive-perceptual model developed to explain the pitch perception of brief acoustical stimuli. Successive chapters review relevant research and describe the proposed cognitive-perceptual model in detail.

## CHAPTER II

### EXPERIMENT I

In all of the studies cited in the preceding review, the physical intensities of the signal and interfering tone have been of equal values. Auditory stimuli occurring within the context of speech or music can vary considerably in intensity. For example, the sound associated with consonants is almost always of a different intensity than that associated with vowels (Stevens & House, 1972). Furthermore, relative amplitude is one of the critical variables in the discrimination of consonant sounds, especially the voiced and voiceless fricatives (e.g., Heinz & Stevens, 1961). The intensity variable is also of crucial importance in the perceptual model of Massaro (1972a). In fact, it is the result of assumptions regarding relative intensity that Massaro differentiates his model from others. Thus, the question of relative intensity has wide-ranging relevance.

There exists a rather extensive body of literature which indicates that the ability of human subjects to resolve the frequency of an auditory stimulus can be a function of stimulus intensity. Examples of research which has employed some measure of frequency discriminability as the dependent variable and stimulus intensity as the manipulated variable follow.

Shower and Biddulph (1931) represent a classic example of the

relationship between frequency discriminability and physical intensity. They found that the frequency difference limen (minimum discriminable difference or DL) was inversely related to sensation level.

Turnbull (1944), while investigating the time-intensity interaction, manipulated the amplitude of standard and comparison tones of 35 msec duration in the determination of DL's for frequency. The standard tone remained constant at a frequency of 1024 Hz across intensity values of 20, 30, 40, 60, and 80 dB above threshold. The general finding was that the DL decreased as the intensity of the stimuli increased (although there was a reversal of small magnitude at 80 dB).

This general conclusion was also reached by Pikler and Harris (1955), who utilized tones of longer duration (1.4 secs). Using a psychophysical procedure similar to that of Turnbull, Pikler and Harris measured the DL for frequency (1000 Hz) at sensation levels of 5, 10, 15, 20, and 30 dB. Here too, DL decreased as intensity increased. The primary purpose of the Pikler and Harris study was to compare DL's obtained by way of different auditory channels (i.e., right ear, left ear, both ears). They found that when the channels were equated for loudness, differences in channel DL's were eliminated. This result was also found in the following study.

Gebhardt, Goldstein, and Robertson (1972) obtained DL's with a 2AFC procedure for frequency values of 200, 300, 500, and 1000 Hz and varying intensities. They concluded that DL's decreased with increases in intensity and that differences between DL's could be reduced by equating signal loudness.

Regarding relative intensity, Harris (1947), using a 2AFC paradigm,

manipulated the level of a continuous noise mask such that the ratio of a 250 msec, 1000 Hz signal to noise background was varied as DL's were obtained. His finding was that DL's increased as signal to noise ratios decreased. This study, with its interfering stimulus, strongly suggested that relative intensity is a variable that should be investigated using the backward recognition interference paradigm.

The preceding sample of studies investigating frequency resolution as a function of absolute intensity and relative intensity indicates that these variables may be important in providing a more complete understanding of the auditory processing of brief, potentially degraded, acoustical stimuli.

The purpose of Experiment I was to discover whether changes in the physical intensity relationship between a brief (20 msec) signal and a subsequent, longer duration (500 msec) interfering tone would result in concomitant changes in the ability to accurately perceive the pitch characteristics of the brief duration signal. It was expected, on the basis of existing research relating intensity to frequency difference limens, that the minimum frequency difference required for a given performance level (e.g., 75% correct) would decrease as the intensity of the signal relative to that of the interfering tone increased.

Because the possibility existed that different "degrees" of discriminability might be affected differentially as relative intensity was varied, frequency differences that corresponded to three levels of performance (50-55%, 70-75%, and 90-95%) were employed. Since the smallest of these frequency differences was in excess of that required for 100% performance when the signal occurred in the absence of an

interfering tone, the possibility existed that a merging of the three performance curves would occur when the intensity of the signal exceeded a certain value. That is, at some value of relative signal-interfering tone intensity, a "release from interference" was expected (see Figure 2).

An understanding of predictions derived from Massaro's cognitive-perceptual model requires a closer look at that model. Massaro (1972a) described the existence of a hypothetical construct which he termed the "pre-perceptual acoustic store" or PAS. The function of this short-term, or echoic, memory structure was to preserve an identical trace or representation of a recently terminated, brief duration acoustical stimulus until that time when the contents of the PAS made "contact" with a higher level, meaning assigning, memory. That is, until a stimulus made contact with the higher level memory system, no estimates of the pitch characteristics, for example, of the stimulus could be attained. Research by Massaro (1970) indicated that the time course of the contact process between the PAS and higher memory was about 250 msec for the pitch identification of 20 msec tonal signals. If a subsequent acoustical stimulus occurred within the 250 msec required for identification, this trailing stimulus would effectively "write over" the resident contents of the PAS, thereby resulting in a decrement in signal pitch perception.

Regarding the relative intensities of the signal and interfering tones, Massaro (1972a) stated that unequivocal proof of the existence of the PAS could be obtained only under conditions of equal signal-interfering tone "loudnesses." If an interfering tone is "louder" than the signal, it proceeds more quickly through the neural pathways,

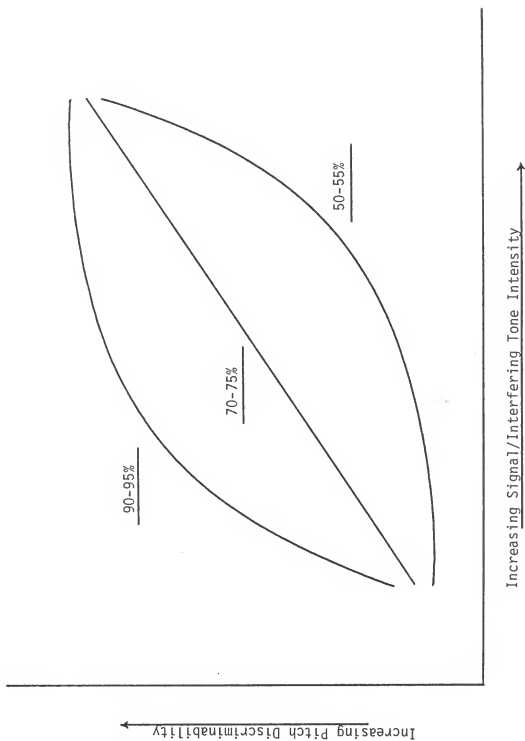


Figure 2. Predicted Change in Pitch Discriminability as a Function of Changing Signal/Interfering Tone Relative Intensity for Three Base Performance Levels.

"overtakes" the signal, and reduces the "signal to noise ratio." Therefore, the signal becomes more difficult to detect (or hear) and decrements in pitch perception are the result of this new, more difficult to hear signal and not necessarily to an interference of the processing of the frequency of the signal.

This position would imply that, in Experiment I, when the signal is less intense than the interfering tones, the minimum frequency difference required for a given performance level should be greater than when the tones are of equal intensity. However, when the signal exceeds the interfering tone in intensity, predictions become less clear. If a decrement in performance when the interfering tone is the more intense is the result of a decreased signal to noise ratio (and therefore a problem of detection), an increased signal to noise ratio should also only affect the detection process. In fact, Massaro (1970), in support of the decreased signal to noise ratio notion stated

Assuming that simple reaction time to a tone contains independent detection, decision, and response components (Donders, 1969; Sternberg, 1969), stimulus loudness should only affect the detection component. (p. 126)

While it is true that the simple reaction time task does not require a discrimination between possible stimuli, the fact that Massaro assigns the cause of pitch perception decrement to only a reduced signal to noise ratio implies that frequency resolution is a process independent of detection. (This interpretation is reinforced in Figure 3 which contains a typical block diagram describing the PAS auditory processing system.) This contention would suggest that an increasing signal intensity relative to the interfering tone intensity

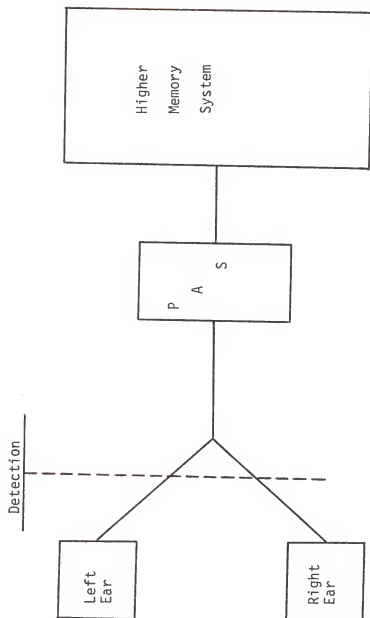


Figure 3. Massaro's "Pre-Perceptual Acoustic Store" (PAS).

would result in a more easily detected signal, but not necessarily in a more accurately perceived pitch of that signal.

There is another point of Massaro's model which would suggest no improvement in performance when the signal exceeded the interfering tone in intensity. That is, because a signal is not perceived to be "high" or "low" in pitch until contact is made with a higher level memory, it is not clear why the contact should be facilitated by a more intense signal. Massaro (Note 1) has stated that the representation in higher memory with which the trace contained in the PAS must make contact can change as a function of practice, experimental context, and differences along dimensions other than pitch. Thus, why should the representation corresponding to intense signals be "contacted" more readily than the representation corresponding to less intense signals at the same signal frequency difference? While it is difficult to believe that Massaro himself would fail to predict an increase in performance with increasing signal to noise ratios, his model is clearly ambiguous in this regard.

### Method

#### Subjects

A total of four undergraduates (2 males, 2 females) with normal hearing and ranging in age from 20-24 years served as subjects. Each was paid an hourly rate of \$2.00.

#### Stimuli and Equipment

A single-interval paradigm was utilized with a signal duration of 20 msec and an interfering tone duration of 500 msec. The interstimulus

interval remained constant at a value that has reliably produced interference effects across studies, i.e., 5 msec. The interfering stimulus was a zero-gated sinusoid of 800 Hz, with the two possible signals similarly gated and of frequencies symmetrical about 800 Hz. The intensity of the interfering tone was 70 dB (SPL) throughout Experiment I, whereas the intensity of the signals was varied across values of 52, 61, 70, 79, and 88 dB (SPL). This range of signal intensities represents a septupling of physical pressure and reflects the intensity extremes of extant studies. Thus, a total of five conditions was included in Experiment I which resulted in signal to interfering tone differentials of -18, -9, 0, +9, and +18 dB.

The signals were produced by two General Radio signal generators (Model 1313-A), with the interfering tone produced by a Wavetek signal generator (Model 171). The durations of, and the interval between, the signal and interfering tone were controlled by computer activated electronic switches (Communication Sciences) which produced essentially instantaneous (0 msec) rise-decay times. The tones were presented binaurally via Grason-Stadler headphones (Model TDH39-300Z) to two subjects simultaneously who were seated in an Industrial Acoustics chamber. Responses were recorded and tabulated on a Digital PDP-8/e.

#### Procedure

On a given trial, a one-second warning light was activated on the subjects' console which indicated that one of two equiprobable signals would occur one sec after the light's termination. The 20-msec signal was followed after an interval of 5 msec by the 800 Hz, 500-msec interfering tone (see Figure 4). The subjects' task was to indicate

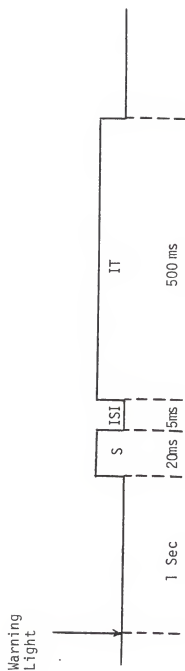


Figure 4. Temporal Relationship of Warning Light, Signal (S), Interstimulus Interval (ISI), and Interfering Tone (IT).

by depressing one of two response buttons (within a 3-sec response interval) whether the signal that had occurred was above or below the interfering tone in pitch (i.e., "high" or "low"). After a response was made, the accuracy of the response was related to the subject by way of the illumination of one of two feedback lights. The total amount of time required for the preceding sequence of events was about 7 secs. Therefore, each block of 50 trials lasted approximately six minutes. Experience indicated that a five to ten minute rest period after every six, 50-trial blocks was a requisite for stable (less than 5% variability) performance.

Each subject participated in a minimum of three, one and one-half hour sessions of practice (approximately 2500 trials) for the purposes of task familiarization and the determination of the individual frequency difference values that corresponded to performances of 50-55%, 70-75% and 90-95% correct at equal signal and interfering tone intensities--70 dB (SPL). (See Appendix for an account of the computation of "per cent correct,"  $P(C)$ .)

After performance stabilized, the collection of data began. Within each of the levels of performance (50-55%, 70-75%, and 90-95%), the intensity of the signal relative to the constant intensity interfering tone was manipulated in a blocked fashion with all intensity differentials being completed before the next performance level was begun. For example, if it was found during the practice sessions that a subject required a frequency difference of 40 Hz to respond consistently correctly 70-75% of the time (when the signal and interfering tones were both 70 dB), equiprobable signals of 780 Hz and 820 Hz were presented at, for example, 61 dB, and performance was recorded.

After the five conditions of signal to interfering tone intensity differentials were completed, the next performance level was begun. The order of presentation of the three performance levels, as well as the five conditions of intensity differences within each performance level, was randomly determined. When beginning a different intensity relationship condition within a performance level, two blocks of 50 practice trials were presented before data were recorded. Then, the following four 50-trial blocks were tabulated and constituted the datum point for that condition.

At the end of each session, conditions completed earlier in the experiment were re-checked for possible practice effects. In no instance did these re-checks reveal an improvement in performance exceeding the limits of criterial variability (i.e., 5%). Responses were converted to values of  $d'$  (see Appendix) and were plotted as a function of changing signal to interfering tone intensity differentials at points corresponding to the three base performance levels.

### Results

The results for individual subjects are presented graphically in Figures 5 and 6 and tabularly in Table 2. The ability to perceive the pitch of the signals (as measured by  $d'$ ) generally increases for all levels of base discriminability as a function of increasing signal to interfering tone intensity differentials. It can be seen that, while individual differences do occur, overall trends are similar across subjects. One exception, however, is the departure from the norm for all performance levels in the 88/70 condition for Subject mm ( $S_{mm}$ ).

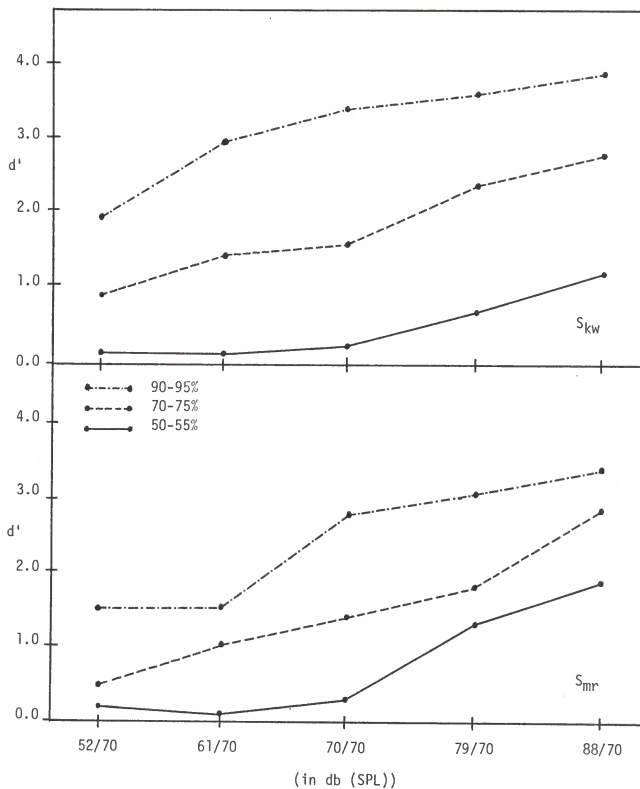


Figure 5. Changes in Pitch Discriminability ( $d'$ ) as a Function of Changes in Signal/Interfering Tone Intensities for  $S_{kw}$  and  $S_{mr}$ .

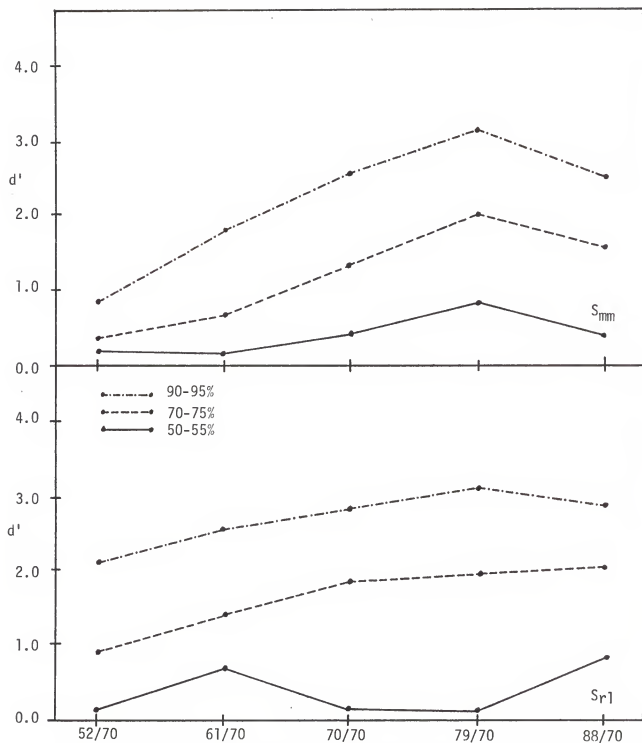


Figure 6. Changes in Pitch Discriminability ( $d'$ ) as a Function of Changes in Signal/Interfering Tone Intensities for  $S_{mm}$  and  $S_{rl}$ .



Questioning of  $S_{mm}$  revealed that the 88 dB, 20-msec signal was auditorally noxious, which precluded optimal pitch processing. This remained the case even after 1000 trials were attempted. (A similar situation arose for different subjects in Experiment II.) Nonetheless,  $S_{mm}$ 's data were incorporated into the mean results presented in Figure 7. Figure 7 and Table 3 contain the mean values of  $d'$  as a function of changing signal to interfering tone intensity differentials. Also listed are the obtained  $P(C)$  values for each performance level, as well as the associated mean  $\Delta f$  values. In addition to the preceding conditions, the frequency difference limen under interference-free conditions was calculated during the initial practice sessions. This mean value of 10.25 Hz corresponded to a  $P(C)$  of .75 and a  $d'$  value of 1.00.

### Discussion

The results obtained in Experiment I clearly indicate an orderly increase in pitch perception performance ( $d'$ ) across all levels of base performance as a function of increasing signal to interfering tone intensity differentials. However, it should be noted that a total "release from interference" was not obtained even when the signal was 18 dB more intense than the interfering tone, although the trend was in that direction. (This trend is more apparent when the data for  $S_{mm}$  are not included in the mean results.) It is doubted that a continuation of the increase in signal intensity would have resulted in a merging of the three performance curves (as predicted in Figure 2), since at levels much above 90 dB (SPL) the sensation of the 20-msec signal is capable of eliciting a protective contraction of the middle

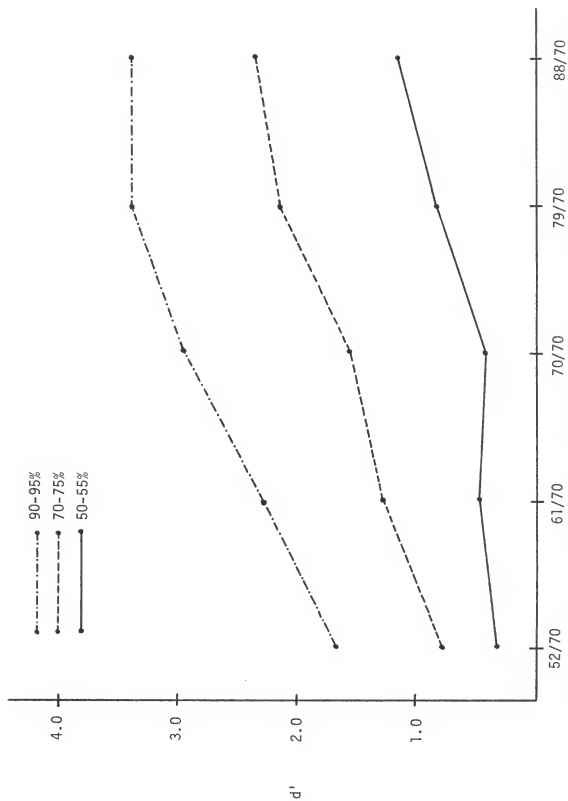


Figure 7. Mean Changes in Pitch Discriminability as a Function of Signal/Interfering Tone Intensities.

Table 3. Mean Values of  $\Delta f$ ,  $P(C)$  ( $\times 100$ ), and  $d'$  for the Three Base Levels of Performance as a Function of Signal/Interfering Tone Intensity.

|                 |        | Performance Level |         |         |
|-----------------|--------|-------------------|---------|---------|
|                 |        | 50-55%            | 70-75%  | 90-95%  |
| $\Delta f$      |        | 11.5 Hz           | 35.0 Hz | 75.0 Hz |
| Condition 88/70 | $P(C)$ | 77.00             | 89.00   | 98.00   |
|                 | $d'$   | 1.21              | 2.44    | 3.35    |
| Condition 79/70 | $P(C)$ | 65.00             | 84.00   | 96.60   |
|                 | $d'$   | .87               | 2.13    | 3.35    |
| Condition 70/70 | $P(C)$ | 55.10             | 76.80   | 91.30   |
|                 | $d'$   | .36               | 1.57    | 2.99    |
| Condition 61/70 | $P(C)$ | 57.10             | 71.50   | 85.70   |
|                 | $d'$   | .39               | 1.21    | 2.26    |
| Condition 52/70 | $P(C)$ | 54.00             | 63.00   | 78.30   |
|                 | $d'$   | .34               | .75     | 1.65    |

ear muscles ("middle ear reflex") which could itself interfere with the processing of the pitch of the signal. Had the base level of the signal and interfering tone begun at a value less than 70 dB, perhaps a merging of the curves would have occurred at signal to interfering tone intensity differentials greater than 18 dB. While a total release from interference was not obtained, a careful look at the  $d'$  value of the 50-55% curve at the 88/70 point (see Figure 7), however, reveals that pitch discrimination had reached a level approximately equal to the mean difference limen obtained under interference-free conditions. That is, when the signal was 18 dB more intense than the interfering tone, the mean  $d'$  value of 1.21 (at a  $\Delta f$  of 11.5) is comparable to the  $d'$  value of 1.0 (at a  $\Delta f$  of 10.25) that was obtained under interference-free conditions. This suggests that there was at least a partial release from interference at this intensity difference.

Regarding the derived predictions from the PAS model of Massaro (1972a), these results suggest that a more precisely worded statement of the nature of the representation of the stimulus in memory and its contact with the contents of the PAS is required, especially in cases where the signal is more intense than the interfering tone. That is, as noted earlier, Massaro would predict that in those conditions in which the interfering tone was more intense than the signal (conditions 52/70 and 61/70), the interfering tone would overtake the signal in the processing pathways and effectively reduce the "signal to noise ratio," thereby rendering the detection of the presence of the signal more difficult. This degradation of the signal is presumably independent of interference with the perception of the pitch of the signal. In those conditions in which the presence of the signal is readily detectable

(conditions 79/70 and 88/70), the improvement in the pitch discrimination observed under those conditions can only be explained by facilitated contact with higher memory by more intense signals residing in the PAS. Massaro's model does not presently contain this stipulation.

It appears, therefore, that an increase in the intensity of the signal relative to that of the interfering tone results in an increased ability to accurately perceive the pitch of the brief duration signals. However, the possibility exists that this increase in performance is simply the result of an increasingly intense signal (given the inverse relationship between the frequency difference limen and intensity) and not necessarily to an increased signal to interfering tone intensity differential. Experiment II investigates this possibility.

## CHAPTER III

### EXPERIMENT II

As noted in the literature review in Chapter II, the ability to discriminate tones on the basis of pitch improves with increases in the absolute physical intensities of the tones (Gebhardt, Goldstein, & Robertson, 1972; Pikler & Harris, 1955; Shower & Biddulph, 1931; Turnbull, 1944). These studies were conducted utilizing tones that occurred in the absence of any type of acoustical interference and indicate that the absolute intensity of the acoustical stimulus is important in increased pitch discriminability. That is, the results obtained in Experiment I could be due primarily to a varying signal intensity, with relatively little effect being exerted in the presence of the interference tone.

Research by others (e.g., Harris, 1946, 1947) has shown the pitch discriminability of tones in the presence of acoustical interference to be a function of the relative intensities of the signal and interfering stimulus. Harris (1946) found that the discriminability of the pitch of tones in the presence of thermal noise increased with increases in the signal/noise differential, even though the absolute intensity of the signal remained constant. Similar results were obtained by Harris (1947) in a study in which he sought to replicate and expand his earlier findings. The implication of these and similar findings is that the results of Experiment I were due to changes in the relative

intensities of the signal and interfering tone. Experiment I, however, differs from the studies by Harris on several points:

1. The Harris studies presented signal and noise simultaneously, whereas the signal and interfering tone in Experiment I were temporally discrete.
2. Harris employed thermal noise as the interfering stimulus, whereas Experiment I utilized pure tones.
3. The noise in the Harris studies was present continuously and was the manipulated stimulus, whereas the intensity of the signal remained constant. The possibility that auditory fatigue (from prolonged exposure to the thermal noise at 60 dB above threshold) would affect signal pitch discrimination was considered. However, tonal threshold checks on a percentage of the subjects revealed no significant threshold shifts. Nonetheless, Experiment I was not subject to this criticism, since interfering tone presentation was intermittent while the signal intensity was the manipulated variable.

Clearly, however, the findings of Experiment I are subject to two possible interpretations. The changes in pitch discriminability could be the result of changes in the absolute intensity of the signal or the result of a varying signal and interfering tone intensity differential. The purpose of Experiment II was to determine which of these explanations was correct. This intent was accomplished by varying the absolute intensities of the signal and interfering tone while maintaining a constant relative intensity relationship. If the absolute intensity interpretation were operative in this situation, one

could expect changes in pitch discrimination similar to those obtained in Experiment I. On the other hand, if relative intensity were the critical variable, no change in discriminability across conditions would be expected.

### Method

#### Subjects

Two female subjects (aged 20 and 21 years) participated in Experiment II. Subject kw ( $S_{kw}$ ) completed Experiment I, whereas Subject sr ( $S_{sr}$ ) began Experiment I but failed to complete it due to illness. As in Experiment I, both were paid an hourly rate of \$2.00.

#### Stimuli and Equipment

All tones, durations, and intervals were the same as in Experiment I. The intensities of the signal and interfering tone, however, were always identical across five values--52, 61, 70, 79, and 88 dB (SPL). That is, the signal to interfering tone intensity differential remained constant at a value of 0. The tones, durations, and responses were generated, controlled, and tabulated using the same equipment and methods as in Experiment I.

### Procedure

For reasons of economy, only one frequency difference value was used--40 Hz. For  $S_{kw}$  this corresponded to a  $d'$  value of 2.47 in the 70/70 condition. For  $S_{sr}$  the 780 and 820 Hz tones were accurately perceived at a level corresponding to a  $d'$  value of 1.18 when the signal and interfering tone were equal at an intensity of 70 dB. Therefore,

some information was provided regarding possible differential performance level effects as a function of changing tonal intensities.

The sequence of events constituting a trial in Experiment I remained the same for Experiment II. Similarly, 50 trials constituted a trial block, with a rest period occurring after every six blocks. Because the subjects were already familiar with the procedure, 300 initial practice trials resulted in a less than 5% variability rate between successive trial blocks. The five conditions of signal/interfering tone levels (52/52, 61/61, 70/70, 79/79, and 88/88 dB) were presented in a blocked fashion, with the order of presentation determined by chance. Each condition was completed and the results were tabulated before beginning the next condition. Before recording data for a successive condition, 100 trials of practice at that signal/interfering tone intensity were presented. The successive four blocks (200 trials) comprised the test data for that condition. As in Experiment I, previous data points were re-checked at the end of each session.

### Results

Figure 8 displays the individual subject's ability (as reflected by values of  $d'$ ) to discriminate the 780 Hz and 820 Hz tones as a function of increasing signal/interfering tone intensity. (The calculation of  $d'$  was the same as in Experiment I.)  $S_{sr}$  maintains a constant level of performance across conditions, whereas the performance of  $S_{kw}$  is essentially flat except for condition 52/52 where  $d'$  falls from a value of approximately 2.62 to a value of about 1.36. This point for  $S_{kw}$  was re-tested during different sessions and remained essentially unchanged.

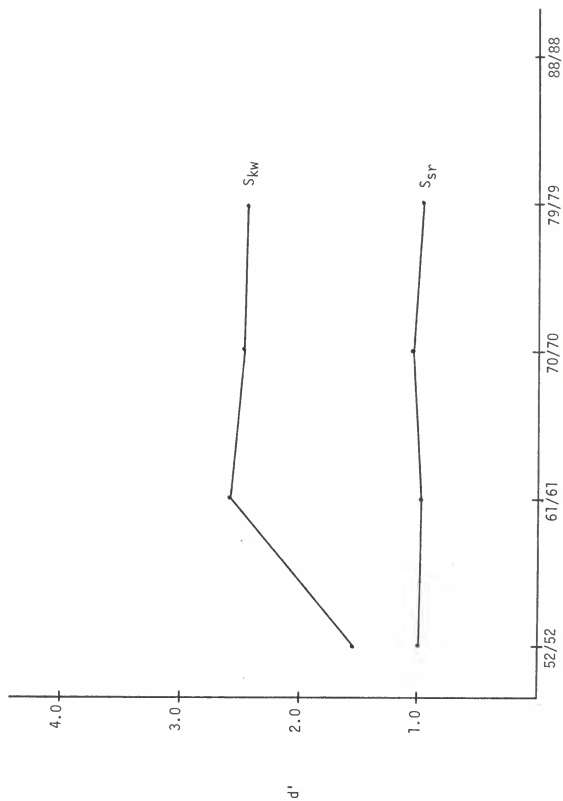


Figure 8. Changes in Pitch Discriminability as a Function of Signal/Interfering Tone Intensities.

Obvious omissions in Figure 7 are the points for the 88/88 condition. Both subjects were unable to tolerate even the presentation of the signal and interfering tone at this intensity. Observation of the subjects by the experimenter revealed partial eyeblinks at stimulus array onset. This "startle" response, combined with a possible middle ear reflex, potentially confounded the processing of the pitch of the signal independent of the typical interfering effects of the interference tone. Therefore, the 88/88 condition was unobtainable.

### Discussion

The results of Experiment II indicate that the changes in pitch discriminability obtained in Experiment I were due to changes in the relative intensities of the signal and interfering tone and not simply to the varying absolute intensity of the signal.

For  $S_{sr}$  there was virtually no change in pitch discrimination as the absolute intensity of the signal was varied from 52 dB to 79 dB (with relative intensity held constant). Because  $S_{sr}$  did not complete her participation in Experiment I, comparisons across similar absolute signal intensity values cannot be made. However,  $S_{kw}$ , whose pitch discriminability remained essentially constant across conditions 61/61, 70/70, and 79/79 in Experiment II, had shown an increase in performance from a  $d'$  value of 1.49 at the 61/70 condition to a  $d'$  value of 2.49 at the 79/70 condition in Experiment I. The decrease in pitch discriminability for  $S_{kw}$  at the 52/52 condition probably reflects individual differences similar to those that occurred for the subjects in Experiment I.

The results of Experiments I and II indicate that, in the backward

interference pitch recognition paradigm, an improvement in the discriminability of the pitch of brief tonal signals improves with increases in signal/interfering tone intensity differentials. This improvement occurs for different degrees of pitch discriminability and is due to relative intensity relationships and not solely to the absolute intensity of the signal.

Regarding Massaro's (1972a) PAS model, the results of Experiment II are in general agreement with a basic assumption of the model. That is, since the signal and interfering tone were of identical physical intensities, they should theoretically proceed along the processing pathways at the same rate, thereby precluding an "overtaking" of the signal in the neural pathways by the trailing interference tone. Thus, the signal traces in the PAS in each of the four observed conditions of Experiment II should be subject to comparable amounts of "overwriting" or interference and should display similar amounts of discriminability. On the other hand, the subjective experience of the signal in the 52/52 condition is different from the experience of the signal in the 79/79 condition, for example. Since one might expect the representations residing in higher memory to be different also, (Massaro (Note 1) admitted this probability), at least along the dimension of overall loudness, it is interesting that contact with the contents of the PAS was similar for all the condition-specific representations. Returning to the results of Experiment I in which signals more intense than the interfering tone were perceived more accurately, it was noted that it was not clear why higher memory representations for more intense signals should be contacted with the contents of the PAS more readily

than less intense signals (since "loudness" according to Massaro, should only affect the detection process which is independent of pitch perception operations). The results of Experiment II indicate that the PAS representations for signals of different intensity do not contact memory differentially. To explain the results of Experiment I would require that they do. Thus, Massaro's assumption that relative intensity is important only in the detection process may be in jeopardy. Another assumption of the PAS model is that the subjective intensities (loudnesses) of the 20-msec signal and the 500-msec interfering tone are equal. Experiments III and IV examine this assumption.

## CHAPTER IV

### EXPERIMENTS III AND IV

As noted in preceding chapters, Massaro (1972a) has postulated the existence of a buffer or memory structure located in the auditory processing system that "holds" a trace of a recently terminated acoustical stimulus until that "echoic" representation is given meaning by a higher, centrally located memory. The notion of an "echoic" memory which preserves a functionally identical representation of a recently terminated acoustical stimulus is not a new one. For example, "stimulus trace" (Hull, 1952), "raw storage" (Yntema, Wozencroft, & Klem, Note 2), "echoic memory" (Neisser, 1967), "auditory information storage" (Sperling, 1967), and "pre-categorical acoustic store" (Crowder & Morton, 1969) are all terms that have been coined to describe the persistence of a sensory stimulus. Massaro (1972a), however, differentiates his model from these and others on the basis of the methods utilized to derive them. Of critical concern in this regard are the relative intensities of the signal and masking or interfering stimuli. Massaro (1972a) argues that a more intense interfering stimulus proceeds more quickly along the processing pathway, and can potentially "overtake" a recently terminated signal, thereby reducing the effective "signal to noise ratio." As mentioned earlier, a decrement in the frequency discriminability of the signal under these conditions may, according to Massaro, be due to a more difficult to detect signal and not necessarily to an interference with a pitch processing system.

That more intense signals are reacted to more quickly (whether because of an increased neural discharge rate or an increased number of neurons discharging) is not being contested here. The inverse relationship between simple reaction time and stimulus intensity had been noted by Bessel soon after Maskelyne's 1794 discovery of the "personal equation" (cited in Fitts & Posner, 1969, p. 84) and has since been repeatedly observed (e.g., McGill, 1961). What is being questioned is the manner of Massaro's use of this relationship to prove that the 20-msec signal and 500-msec interfering tone enjoy similar levels of subjective intensity or loudness. The proof of this equal loudness assumption is of fundamental importance in the differentiation of Massaro's cognitive-perceptual model from other, more psychophysical, detection models, for example.

Before reviewing Massaro's proof of equal signal-interfering tone loudnesses, a look at some of the variables that are important in determining auditory loudness is warranted.

#### Loudness as a Function of Stimulus Duration

The relationship of intensity and duration in the processing of an auditory stimulus has been studied for many years (e.g., Hughes, 1946; Munson, 1947). Early questions surrounding the time the auditory system requires to integrate ("temporal integration") acoustical stimulation resulted in the development of an "equal energy" hypothesis. That is, since energy is equal to power divided by time, a change in power would require a concomitant (but opposite) change in time to maintain an unchanging energy value. Regarding the detection of a signal, it was found that decreasing the power of the signal by 10 dB required an

increase in the duration of the signal in the detection task by almost one log unit (out to about 250 msec) for constant performance. Therefore, the 20-msec signal commonly used in the backward interference pitch recognition paradigm would have to be increased by between 11 and 14 dB (depending upon signal frequency) to reach the same threshold level as the 500-msec interfering tone of similar frequency (assuming a perfectly linear integrating mechanism).

Regarding subjective intensity, equal loudness contours relating stimulus duration at a given intensity to the subjective experience of loudness also suggest that a stimulus of 500 msec would be perceived to be louder than a 20-msec stimulus. For example, Stevens and Hall (1966) found that, across all base levels of physical intensity (other than threshold), a 20-msec burst of white noise had to be 10-11 dB (SPL) more physically intense than a 500-msec noise stimulus to be perceived equal in loudness. Comparable results for 1000 Hz tones were obtained by Wright (1965) and McFadden (1975).

Thus, on the basis of the preceding psychoacoustical findings, the possibility exists that the brief duration signal and the longer duration interfering tone used in the development of Massaro's PAS model may not be of equal loudness.

A second variable that can affect the perceived loudness of an acoustical stimulus is the presence of additional stimuli.

#### Loudness as a Function of Temporally Proximal Stimuli

When a pair of acoustic clicks of equal physical intensities are presented in close succession and a subject is asked to adjust the intensity of the second click to match the loudness of the first, equal

loudness estimates may result from intensity differences as large as 15 dB (Buytendijk & Meesters, 1942). That is, the second click is perceived to be louder than the first. Furthermore, the degree of this difference decreases with increases in inter-click intervals out to about 200 msec.

Irwin and Zwislocki (1971), using acoustic bursts of 10 msec duration, required subjects to adjust the level of a third, temporally discrete (by 500 msec) burst to match the loudness of the second burst of the pair, the interval between which varied between 0 and 200 msec. With this second dichotic burst, there was a 5-7 dB increase in loudness which decreased to 0 dB when the interstimulus interval was increased to 100 msec.

This enhancement of the loudness of the second of two brief stimuli has been replicated by several investigators (e.g., Elmasian & Galambos, 1975; Scharf, 1971) and the loudness enhancement has been shown to be a function of interstimulus interval, frequency similarity, relative intensities of the two stimuli, etc. The point of importance is that, here again, the possibility exists that the signal and interfering tone in the backward interference pitch recognition paradigm may not be of equal loudness.

Another variable, which will be examined in more detail in Experiment V, deals with the rate at which a stimulus reaches its maximum physical amplitude and has been shown to be related to subjective intensity.

#### Loudness as a Function of Rise-Decay Time

Several investigators have provided evidence indicating that loudness estimates vary as a function of the rise-decay time of the auditory

stimulus (e.g., Gjaevanes & Rimstad, 1972; Kryter & Pearsons, 1963).

The general finding is an inverse relationship between rise-decay time and loudness. Since, in studies relevant to the backward interference pitch recognition paradigm, the signal and interfering tone have had equal value rise-decay times (usually less than 2 msecs), the contribution of this variable to differential loudness effects is probably minimal. However, the responsibility of the rise-decay time variable in contributing to differences between studies is examined in Experiment V.

While none of the studies in the preceding review of loudness-related variables employed a method identical to the backward interference pitch recognition paradigm, the reliability of those results suggests that an investigation into the signal-interfering tone equal loudness assumption would be worthwhile. This point is strengthened after examining the procedures used by Massaro to substantiate the equal loudness assumption. It should be noted that a concerted effort to prove the equal loudness assumption has not been undertaken by Massaro. Rather, Massaro apparently accepts the notion that equal physical intensities yield equal subjective intensities. In those few instances in which the equal loudness assumption is tested, it is often in prelude to answering another question.

The initial justification for the equal loudness assumption occurred as the result of a single experiment reported in Massaro's 1972(b) article. In that article, Massaro calculated simple reaction times (RT) to two possible signals (an 800 Hz sawtooth wave or an 800 Hz sine wave) and to a single "masking" stimulus (in this case, an 800 Hz square wave). He found that RT's to these three stimuli were essentially equal (151, 161, and 154 msecs, respectively). However, these stimuli were apparently

presented on discrete trials, thereby precluding any interactive effects that might have occurred as a result of the temporal proximity of the signal and interfering tone which is characteristic of the backward interference pitch recognition paradigm. Furthermore, it was not possible to determine from Massaro's description whether the signals and interfering tone were of equal or unequal durations. It should also be pointed out that this article was the only instance in which Massaro chose to use sawtooth and square waves in addition to sine waves. This decision was possibly the result of a desire to hold the frequency variable constant while making loudness and perceptual processing time comparisons.

Because of the findings of the psychoacoustical researchers and the apparently insufficient method employed by Massaro to prove the equal loudness assumption, it was decided that a test of the subjective intensities of the signal and interfering tone in the backward interference pitch recognition paradigm should be undertaken. Additionally, it was hoped that ancillary information regarding loudness effects as a function of a stimulus durations and proximity to other stimuli would be obtained. Experiments I and II showed that pitch discriminability was a function of relative physical intensity. Experiments III and IV were designed to determine the subjective intensities of the signal and interfering tone as well as to investigate the relationships between physical intensity, loudness, and pitch discrimination accuracy that operate in the backward interference method.

### Experiment III

Experiment III utilized the traditional psychophysical method of adjustment procedure to estimate the physical intensity of the signal that subjectively "matches" the interfering tone in loudness under three conditions:

Condition 1 - Using the backward interference pitch recognition paradigm, the subject was required to adjust the physical intensity of the 20-msec signal to match the loudness of the interfering tone which followed the signal by 5 msec (see Figure 9).

Condition 2 - Two possible explanations exist for any differences in loudness obtained in Condition 1. That is, a difference in loudness could be due to a retroactive "masking" of the signal by the interfering tone (as in backward detection masking), or the difference could be due to a loudness enhancement of at least the initial portion of the interfering tone (as found by Irwin & Zwislocki (1971), for example). To determine the site of any difference in loudness that may be obtained in Condition 1, the subject was asked to adjust the intensity of the 20-msec signal which preceded the 500-msec interfering tone by 5 msec to equal the loudness of an earlier (by 500 msec) present 20-msec tone (see Figure 9).

Condition 3 - In this condition, to determine whether any loudness difference obtained in Condition 1 was due to a longer duration standard tone, the subject adjusted the intensity of the 20-msec signal to match the loudness of a following (by 5 msec) 20-msec standard tone (see Figure 9).

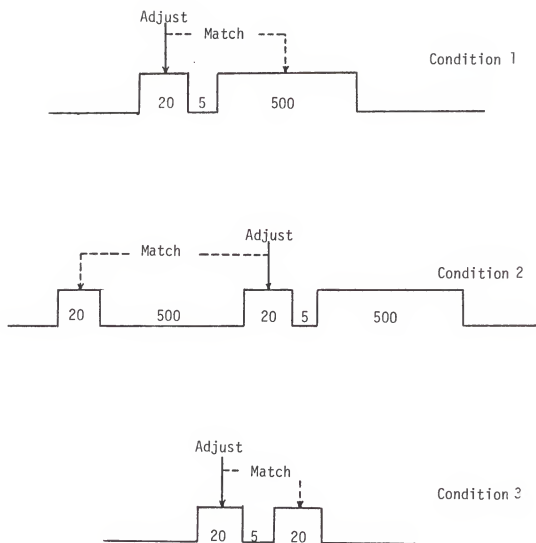


Figure 9. Temporal Relationship of Variable and Standard Tones in Method of Adjustment. (Time in msecs.)

## Method

Subject. The same four subjects that participated in Experiment I took part in Experiment III and received \$2.00/hour for their participation.

Stimuli and equipment. Both the standard and variable stimuli were zero-gated sinusoids of 800 Hz for all conditions. The intensity of the standard stimulus was held constant at a level of 70 dB (SPL) while the intensity of the variable signal was controlled by the subject via a portable Hewlett Packard attenuator (Model 350D). The rise-decay times of the standard and variable stimuli were essentially instantaneous (0 msec).

The stimuli, intervals, and durations were created and controlled by the same equipment as in Experiment I, with the addition of a second attenuator (Hewlett Packard Model 350D) used by the experimenter to vary the starting intensity values of the variable stimulus for successive loudness matching runs.

## Procedures

In each of the three conditions of Experiment III, the task of the subject was to adjust the physical intensity of the 20-msec variable stimulus so that it matched the standard stimulus in loudness. Since all stimuli were of equal frequency, the subjects were instructed to ignore the pitch characteristics of the stimulus array and to concentrate on attaining equal subjective intensity matches.

To help control the possibility of any response bias, the starting intensity of the variable stimulus was randomly varied between successive matches, with the variable stimulus sometimes starting at a physical intensity greater than the standard stimulus and at other times starting at an intensity less than the standard. When the subject was satisfied that

the standard and variable stimuli were of equal loudness, he or she signalled the experimenter and the intensity setting of the variable stimulus was recorded. This procedure was continued until three successive loudness estimates differed by no more than 3 dB. The order of presentation of the three conditions was randomly determined.

### Results

Table 4 contains the individual mean, as well as overall mean, intensity settings of the variable stimulus for the final three runs of each condition. Also included in Table 4 are the range of intensity settings and the standard deviation for the last three runs of each condition. While the overall means for each condition indicated that the intensity of the variable stimulus was adjusted to a higher physical intensity (i.e., greater than 70 dB) to equal the loudness of the standard stimulus, it will be noted immediately that inter-subject differences are in evidence. That is, in Condition 1, for example, two subjects ( $S_{rl}$  and  $S_{mr}$ ) perceived the 20-msec variable signal to be less subjectively intense than the 500-msec standard stimulus (thereby requiring an increment in physical amplitude); one subject, ( $S_{mm}$ ), perceived the two stimuli to be equally loud at equal amplitudes; and one subject, ( $S_{kw}$ ), perceived the 20-msec tone to be louder than the 500-msec tone at equal levels. Similar situations occurred for Conditions 2 and 3, but the differences in perceived loudness were often reversed (between conditions) for individual subjects, though not in an orderly manner. It should be pointed out that while the recorded intra-subject standard deviations were, for most subjects, within the aforementioned criterial range (for three successive trials), it was frequently the case that

Table 4. Individual and Overall Mean Settings of the Variable Stimulus for Conditions 1, 2, and 3.

|             | Mean  | Standard Deviation | Range   |
|-------------|-------|--------------------|---------|
| Condition 1 |       |                    |         |
| $S_{kw}$    | 66.00 | 1.00               | 65 - 67 |
| $S_{mr}$    | 74.25 | 1.15               | 73 - 75 |
| $S_{rl}$    | 78.00 | 2.00               | 76 - 80 |
| $S_{mm}$    | 70.00 | 1.00               | 69 - 71 |
| Overall     | 72.06 | 5.20               | 66 - 78 |
| Condition 2 |       |                    |         |
| $S_{kw}$    | 66.67 | 7.50               | 59 - 74 |
| $S_{mr}$    | 71.00 | 2.00               | 69 - 73 |
| $S_{rl}$    | 67.30 | 1.50               | 66 - 69 |
| $S_{mm}$    | 80.00 | 2.00               | 78 - 82 |
| Overall     | 71.24 | 6.14               | 66 - 80 |
| Condition 3 |       |                    |         |
| $S_{kw}$    | 77.00 | 4.58               | 73 - 82 |
| $S_{mr}$    | 66.33 | 5.69               | 60 - 71 |
| $S_{rl}$    | 74.33 | 1.15               | 73 - 75 |
| $S_{mm}$    | 73.00 | 2.00               | 71 - 75 |
| Overall     | 72.67 | 4.54               | 66 - 77 |

intra-subject variability for all of the estimates for a given condition was outside of the acceptable range. For example in Condition 1, Subject kw estimated the equal loudness intensity of the 20-msec signal to be anywhere from 55 dB to 79 dB over 11 post-practice runs. The standard deviation for these 11 runs was 6.59 dB as opposed to the recorded 1.0 dB standard deviation. It was the opinion of the experimenter that after repeated equal loudness estimates there was a tendency on the part of the subjects to emphasize consistency in their estimates, perhaps at the expense of a concentrated equal loudness effort. For this reason, the reliability and validity of the preceding results are uncertain. Given the suspected invalidity of the preceding results, no statistical tests of significance were undertaken.

### Discussion

The results obtained in Experiment III were of such a nature that the experimenter was reluctant to draw any conclusions regarding the general question of the perceived loudness of a 20-msec signal relative to that of a 500-msec interfering tone. As a result, the answer to the question regarding the site of a difference in loudness was similarly unobtainable. Likewise, answers to related questions regarding the variable deemed important in the perception of loudness (i.e., stimulus duration, temporal stimulus proximity, and rise-decay time), as well as to the relationship between loudness and pitch discriminability in this paradigm, were not determined.

Experiment IV was undertaken to answer some of these relative loudness questions using an alternative experimental method.

### Experiment IV

The purpose of Experiment IV was two-fold. First, because of the difficulty in obtaining unequivocally reliable and valid data concerning the equal loudness question with the method of adjustment procedure of Experiment III, an alternative method was adopted to answer this question. Secondly, it occurred to the experimenter that a more accurate estimate of the subjective intensities of the signal and interfering tone in the backward interference pitch recognition paradigm would be obtained if the procedure of this paradigm were followed more precisely. That is, the method of Experiment IV required the subject to make two perceptual judgments and responses on each trial--the first relating to the pitch of the signal and the second concerning the relative loudness of the signal. A brief pilot study revealed that experienced subjects had no difficulty in completing these two perceptual tasks within the experimental trial time frame (about 7 secs).

Nonetheless, while research has been completed regarding simultaneous inter-modality and inter-channel perceptual judgments (e.g., Broadbent, 1954; Colavita, Note 3; Lindsay & Norman, 1968; Treisman, 1969), little research has been undertaken investigating intra-modality simultaneous perceptual judgments. Therefore, the present study was expected to provide not only information regarding the equal loudness assumption, but also supplemental preliminary data concerning simultaneous perceptual judgment of different dimensions of a single, uni-modal stimulus.

#### Method

Subjects. Subjects kw and sr, who had also taken part in Experiments I and II, participated in Experiment IV and were paid \$2.00/hour.

Stimuli and equipment. The frequency difference ( $\Delta f$ ) of the signals used throughout Experiment IV was 40 Hz, while the interfering tone maintained a constant frequency of 800 Hz. Seven levels of the signal intensity--61, 64, 67, 70, 73, 76, and 79 dB (SPL)--were employed, whereas a constant 70 dB (SPL) interfering tone intensity was utilized. All stimuli were generated and controlled by the same equipment as in Experiment I. In addition, a mechanical counter linked to the response console of each subject was used to tabulate the loudness estimates.

### Procedure

On a given trial, each subject was required to make two perceptual judgments. After stimulus array presentation, the subject first responded to indicate whether the pitch of the 20-msec signal had been the "high" (820 Hz) or the "low" (780 Hz) pitched signal alternative. This response was recorded via the PDP 8/e as in preceding experiments. Immediately after making the pitch judgment, the subject then depressed a different, adjacent response button either once, to indicate the signal had been "softer" in subjective intensity than the interfering tone, or twice, to indicate the signal had been "louder." These loudness judgments were cumulatively recorded during each 20-trial block, so that at a given intensity value an average judgment of 1.5 would reflect the point of subjective equality. Signal intensity was manipulated in three ways: (1) by large (greater than 3 dB) trial by trial signal intensity changes; (2) by small (1 dB) changes that may or may not occur on successive trials; and (3) by a constant signal intensity during a 20-trial block. Because the subject was not cued beforehand regarding which condition would occur for a block of trials, the subject was required to make independent trial by trial loudness judgments. For the purpose of

deriving loudness estimates of the signal, only data collected under condition 3 were tabulated. To help ensure that a subject was not favoring a loudness judgment at the expense of a pitch judgment, only those blocks which resulted in a pitch discriminability performance comparable to that obtained when only a pitch decision was required, were included in the tabulation. For example, since Subject kw had scored a  $d'$  value of about 2.60 at a  $\Delta f$  value of 40 Hz in Experiment II (which was re-tested in Experiment IV), only those trial blocks in which pitch discriminability was between approximately 2.45 and 2.75 were included in the loudness estimate data table.

After the seven, 3 dB-step, signal levels loudness estimates were obtained, another series of four levels in 1-dB increments was completed to define more precisely the point where the signal intensity equalled the interfering tone in loudness.

For all conditions, a minimum of 200 loudness judgments constituted each datum point. The initial session (approximately 800 trials) was utilized to familiarize the subject with the procedure. The order of presentation of all conditions was randomly determined.

### Results

Figure 10 displays the individual loudness ratings (from 1.0 to 2.0) of the signal relative to the interfering tone as a function of relative signal/interfering tone physical intensity. The solid tracing refers to estimates obtained in the 3-dB increment phase, whereas the dashed line reflects the 1-dB increment condition. In all instances, a rating of 2.0 indicates a "louder" judgment 100% of the time, with a value of 1.0 reflecting a 100% "softer" estimate. For Subject kw the point of loudness

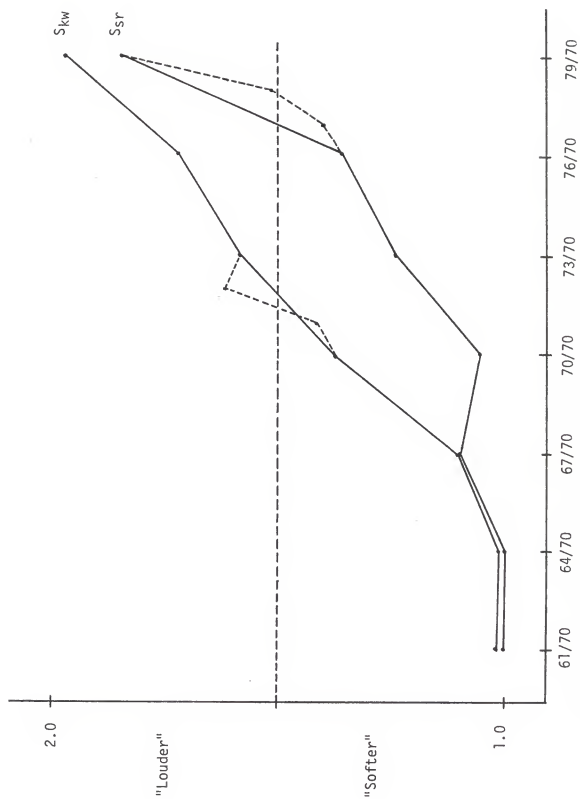


Figure 10. Loudness Estimates of the Signal as a Function of Signal/Interfering Tone Intensities.

equality (i.e., a rating of 1.5) occurred when the signal was at a physical intensity of 71.5 dB. The standard deviation for all blocks bordering this value was about .15. Subject sr's point of equal loudness was about 78.2 dB, with a standard deviation of approximately .20 for this, the most variable area. (The standard deviation for points not immediately adjacent to the point of equal loudness were typically less than .1.)

### Discussion

Using the preceding method, both subjects estimated the signal to be less subjectively intense than the interfering tone at equal physical intensities of 70 dB. However, as with the method of adjustment of Experiment III, the range of signal-interfering tone loudness inequality varied for individual subjects. Somewhat surprisingly, Subject kw, who in Experiment III had set the level of the signal at 66 dB to equal the interfering tone in loudness, in Experiment IV perceived the signal to be equal in loudness to the interfering tone when the signal was at 71.5 dB. This anomalous finding could result from the possibility that being required to make simultaneous dimensional judgments altered the apparent loudness of the signal. On the other hand, this finding could have simply resulted from the employment of a more familiar method in Experiment IV.

While difficulty was experienced in obtaining three successive loudness estimates which varied from each other by less than 3 dB in Experiment III, this criterial variability was easily obtained between all 10, 20-trial blocks representing each point of Experiment IV. For this reason, the experimenter is relatively more confident regarding the results of Experiment IV.

It appears, therefore, that the equal loudness assumption of Massaro's PAS model may require revision. For the two subjects who

participated in Experiment IV, the signal was not of the same loudness as the interfering tone. The generality of this conclusion would require further experimentation, but for these two subjects the possibility that the interfering tone overtakes the signal in the processing pathway (when both are 70 dB) and thereby reduces the signal to noise ratio, is apparent. The implication of this finding to Massaro's PAS model is that decrements in pitch discriminability performance that occur with the backward interference pitch recognition paradigm are not necessarily due to an "overwriting" of the contents of the PAS system. Given this possibility, and borrowing Massaro's criticism of other paradigms, results obtained with this paradigm do not unequivocally prove the existence of a PAS system.

During the 1-dB increment phase of Experiment IV an interesting pitch discrimination-loudness estimate relationship was noted. Analyzing the accuracy of pitch judgments and loudness estimates in a trial by trial fashion revealed a significant ( $\chi^2(1)=12.96, p<.001$ ) tendency for the signal to be rated "softer" on those trials where errors in pitch discrimination occurred. Conversely, the pitch of "louder" rated signals was more accurately perceived. This serendipitous finding suggests that loudness and frequency resolution are not entirely orthogonal. Given this finding, a further analysis of the results obtained in the 3-dB increment phase of Experiment IV was undertaken. Since trial by trial data were not available for this phase, a correlational analysis of relevant variables was performed. First of all, the correlation between signal intensity and loudness estimates was +.72. The correlation between the pitch discrimination ( $d'$ )

performances in 20-trial blocks and their respective physical intensities was  $+0.22$ , averaged across Subjects kw and sr. The correlation between  $d'$  and loudness estimates, however, was  $+0.47$ . Since pitch discrimination was also related to signal intensity, it was necessary to perform a partial correlation, removing the physical intensity variable. This partial correlation was  $+0.46$ . The preceding correlational analysis reveals that the perceived loudness of the signal is more highly correlated with pitch discriminability than simple physical intensity. This finding is not novel, however. It will be remembered that Gebhardt, Goldstein, and Robertson (1972) found that equating signal loudness between channels (ears) resulted in comparable frequency difference limens. Analogously, in the area of visual perception, Boynton and Siegfried (1962), for example, found that the degree of masking of a visual stimulus was more accurately a function of subjective brightness than of physical intensity.

The results of Experiment IV also are relevant to investigations in the area of divided attention. The task of a subject in Experiment IV involved two simultaneous judgments along two different dimensions of a single, brief stimulus. Research that has been completed involving attention that is divided between two channels or modalities has given rise to two general classes of models of attention. One class states that simultaneous stimuli are processed in sequence (serially) and that stimuli not processed first are subject to a decrement in processing (e.g., Broadbent, 1958; Moray, 1967; Treisman, 1964). The other class of research findings suggests that simultaneous stimuli can be processed concurrently (or in a parallel fashion) under at least some conditions (e.g., Deutsch & Deutsch, 1963; Lindsay, 1970; Norman, 1968; Treisman, 1969).

Most of these investigations, however, employed methods involving inter-modality divisions of attention (e.g., visual vs auditory) or attention divided between channels within a modality (e.g., right ear vs left ear). Tests of these two positions utilizing a single channel within a given modality have been relatively few, yet even these have yielded incompatible results.

For example, Lindsay, Taylor, and Forbes (1968) compared the processing of intra- and inter-modality bidimensional stimuli and found that under conditions of poor discriminability ( $d'=.84$ ) there were no differences between the intra- and inter-modality processing, but that both were worse than the condition in which only one perceptual judgment was required. This finding supports the serial notion.

On the other hand, Moore and Massaro (1973) found no decrement in the simultaneous processing of a bidimensional stimulus, thereby supporting the parallel processing notion. Moore and Massaro further concluded that pitch and loudness are independent processes, since a correct response regarding one dimension did not increase the probability of being correct in the other.

Experiment IV differed from the two preceding studies in that there was no "correct" response to the loudness dimension. This method suggested that the two dimensions can be processed accurately (for pitch) and consistently (for loudness) in a seemingly parallel manner, but that the processing of the dimensions of loudness and pitch occurs in a co-related fashion. That is, in contrast to the findings of Moore and Massaro (1973), the response of a subject on the loudness dimension, for example, did alter the probability of him or her being correct on the pitch dimension. This finding is in support of Garner's (1970) idea

of separable vs integral stimulus dimensions which maintains that two integral stimulus dimensions (e.g., pitch and loudness) cannot be treated independently. Rather, integral stimulus dimensions are perceived as units and an improvement in the discriminability of one dimension would be linked to an improvement in the other (p. 354).

The results of Experiment IV, while being quite orderly, are subject to two legitimate criticisms. Since the subjects always responded to the two dimensions in the same order (i.e., pitch, then loudness) the possibility exists that a temporal order bias occurred. Theoretically, however, if the processing of the pitch and loudness of the signal occurs in parallel, a temporal bias effect should only occur as the result of forgetting the perceptual judgment before the response can be recorded. The fact that the time between the registered pitch judgment and the loudness response was typically about one sec reduces this "forgetting" probability. Nonetheless, a more effective experimental procedure would be a counterbalanced response order between subjects.

Related to this response order criticism, is the possibility that the relationship noted between pitch perception accuracy and loudness estimates was due to a tendency on the part of both subjects to estimate the loudness of the signal on the basis of their confidence in their pitch response. That is, on those trials where the pitch of the signal was more apparent (because of a fluctuating signal to noise ratio, attentional accuracy, etc.) the subjects may have simply selected the "louder" response to coincide with the more easily perceived pitch. This explanation could be easily tested by requiring subjects to record their confidence in each pitch judgment and then correlating these confidence ratings with loudness estimates. A positive correlation between

loudness estimates and highly confident correct and incorrect pitch response would suggest that the preceding criticism may be valid. This experiment, however, is left to a future study.

#### Discussion of Experiments III and IV

Experiments III and IV were undertaken to discover the subjective intensity relationship of the signal and interfering tone in the backward interference pitch recognition paradigm. These experiments suggested, with differing degrees of confidence, that the 20-msec signal is not as loud as the 500-msec interfering tone when the two stimuli are of identical physical intensities. The degree of this difference varies for different subjects. Furthermore, Experiment IV indicated that subjects are able to make simultaneous perceptual judgments regarding the dimensions of an intra-modality, single channel stimulus and that the response to one dimension is related to the accuracy of the response to the other.

## CHAPTER V

### EXPERIMENT V

Given the influence on pitch perception that signal loudness exerts, an investigation into variables associated with signal loudness is warranted. As noted in Chapter IV, the duration of a stimulus, as well as its proximity to other stimuli, has been shown by some investigators to be instrumental in determining a signal's subjective intensity. A third variable, stimulus rise-decay time, has been far less extensively studied, but extant research suggests that this variable may be important in determining the perceived loudness of a stimulus.

Vigran, Gjaevanes, and Arnesen (1964) found that, using the method of adjustment, a wide-band noise signal with a 2.5-msec rise-delay time was perceived to be as much as 3.0 dB (SPL) louder than noise signals with longer rise-decay times. These stimuli, however, were of relatively long duration (1 sec) and had rise times which differed from decay times. Similarly, Gjaevanes and Rimstad (1972), using an identical method but employing pure tones as stimuli, also obtained results indicating that rise time was inversely related to perceived loudness. However, this study also used 1-sec duration stimuli and unequal rise and decay times. Other investigators have reported rise time effects on loudness using short-duration clicks (less than 10 msec duration), but these studies were not available for detailed review by this investigator (e.g., Steudel, 1933).

The rise-decay times reported in studies using the backward interference pitch recognition paradigm have ranged from 0 msec (e.g., Yost et al., 1976) to 2.5 msec (e.g., Loeb & Holding, 1975). Unfortunately, however, most studies failed to report specific rise-decay times for the signal and interfering tone. Because it is logical to assume that the signal and interfering tone had equal rise-decay times, a difference in loudness between the two stimuli could not be attributed to this variable. Nonetheless, it is instructive to know whether small differences in rise-decay times in stimuli with parameters comparable to the backward interference pitch recognition paradigm would result in differences in subjective intensity.

The purpose of Experiment V was to discover whether a difference in rise-decay time as small as 3 msec could result in a measurable difference in loudness, independent of frequency, duration, and temporal proximity effects. This study was intended to be exploratory in nature and primarily of heuristic value.

Six conditions comprised Experiment V (see Figure 11). Condition 1 compared the loudness of a 500-msec stimulus with a second 500-msec stimulus, each having a rise-decay time of 3 msec. This condition was included to determine whether these identical stimuli could be matched reliably in the loudness dimension. Condition 2 involved the relative loudness of a 0-msec rise-decay time, 500-msec stimulus compared to a temporally discrete 3-msec rise-decay time, 500-msec stimulus. Condition 3 presented a 20-msec, 0-msec rise-decay time stimulus to be matched in loudness to a 500-msec, 3-msec rise-decay time stimulus. Condition 4 required the matching of a 20-msec signal with a 500-msec stimulus,

Condition 1



Condition 2



Condition 3



Condition 4



Condition 5



Condition 6

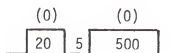


Figure 11. Rise-Decay times (in parentheses) and Temporal Relationships of Variable and Standard Tones for Conditions 1, 2, 3, 4, 5, and 6. (Time in msec; 0-msec rise-decay time is instantaneous within the limits of the switching mechanism.)

each with 3-msec rise-decay times. Condition 5 was identical to Condition 4 with the exception that both stimuli had 0-msec rise-decay times. Finally, Condition 6, using the traditional parameters of the backward interference pitch recognition paradigm, was included as a comparison to results obtained in Condition 4 to provide a preliminary look at the temporal proximity variable, as well as for the purpose of providing a check of loudness estimates obtained in preceding experiments.

### Method

#### Subjects

Three female subjects who had participated in earlier experiments served as subjects in Experiment V and were paid \$2.00 per hour.

#### Stimuli and Equipment

All stimuli were 800 Hz, zero-gated sinusoids, the durations of which were computer-controlled. The amplitude of the second, standard tone was constant at 70 dB (SPL), with the starting intensity of the variable stimulus experimenter-controlled. The interstimulus interval was 500 msec for Conditions 1-5, and 5 msec for Condition 6. All stimuli and intervals were generated as in preceding experiments. Rise-decay times were established by Communication Sciences switches and measured on a Tektronics (Type 3A72) oscilloscope.

### Procedure

Subjects controlled the physical intensity of the variable stimulus by using a 1 dB-step attenuator that was controlled by depressions of the "louder" and "softer" buttons on the subject's console. This

method was chosen in favor of the use of the portable attenuator employed in Experiment III. Each subject practiced that task approximately two hours before data were collected and continued equal loudness estimates for each condition until three consecutive estimates varied by no more than 3 dB (SPL). The order of presentation of the six conditions was randomly determined within subjects.

### Results

Table 5 contains the individual and overall means of physical intensity settings of the initial variable stimulus that was perceived to equal the second, standard stimulus in loudness for Conditions 1-6. Table 5 also includes the associated standard deviations for each condition. The overall mean value of Condition 1 (70.57 dB) indicates that the subjects were able to match accurately the loudness of two identical, temporally discrete stimuli with this method. A decrease in the rise-decay time of the variable stimulus from 3 msec to 0 msec (Condition 2) resulted in an overall increase in subjective intensity of 1.57 dB (reflected by the "softer" setting of the physical intensity of the variable stimulus). Conditions 3 and 4, which employed the 20-msec variable stimulus, showed an increase of 4.94 dB in loudness when the rise-decay time was decreased from 3 msec to 0 msec. While both of these loudness changes were in the predicted direction, neither mean difference was statistically significant (as tested by a one-way, repeated measures analysis of variance). Conditions 5 and 6, which were included to provide a preliminary look at the effects of the temporal proximity variable, indicated that by decreasing the interval

Table 5. Individual and Overall Mean Settings of the Variable Stimulus for Conditions 1, 2, 3, 4, 5, and 6. (Standard deviations are within parentheses.)

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|                 | <u>Condition 1</u> | <u>Condition 2</u> |
|-----------------|--------------------|--------------------|
| S <sub>mr</sub> | 69.50 (0.55)       | 68.00 (0.00)       |
| S <sub>kw</sub> | 72.20 (1.10)       | 69.00 (0.00)       |
| S <sub>sr</sub> | 70.00 (0.00)       | 70.00 (0.00)       |
| Overall         | 70.57 (1.43)       | 69.00 (1.00)       |
|                 |                    |                    |
|                 | <u>Condition 3</u> | <u>Condition 4</u> |
| S <sub>mr</sub> | 72.50 (0.58)       | 69.00 (0.82)       |
| S <sub>kw</sub> | 73.00 (0.00)       | 68.00 (1.40)       |
| S <sub>sr</sub> | 80.00 (0.82)       | 73.67 (1.53)       |
| Overall         | 75.12 (4.19)       | 70.22 (3.03)       |
|                 |                    |                    |
|                 | <u>Condition 5</u> | <u>Condition 6</u> |
| S <sub>mr</sub> | 73.00 (0.00)       | 75.00 (0.00)       |
| S <sub>kw</sub> | 70.00 (0.00)       | 73.00 (0.00)       |
| S <sub>sr</sub> | 74.00 (0.00)       | 77.30 (2.50)       |
| Overall         | 72.33 (2.08)       | 75.10 (2.15)       |

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between the variable and standard stimuli from 500 msec to 5 msec, a decrease in the loudness of the variable tone of 2.77 dB was obtained.

### Discussion

This pilot study indicates that a more comprehensive investigation of the effect of rise-decay time on subjective intensity should be undertaken. Two inter-condition comparisons (Condition 1 vs 2 and Conditions 3 vs 4) showed a consistent (though statistically non-significant) increase in signal loudness with decreases in rise-decay times for a majority of subjects.

The relatively greater increase in loudness with decreasing rise-decay times for the Conditions 3 vs 4 comparison suggests that briefer duration stimuli are affected more from rise-decay time changes than longer duration stimuli. This may be due to the fact that the spread of energy that occurs as the result of onset transients contributes a higher percentage of judgmental information for the 20-msec stimulus than for the 500-msec stimulus. This finding is also congruent with derived predictions from a proposed explanation of the rise-decay time-loudness relationship. Goldstein and Kiang (1958), for example, found that a relatively greater synchrony of "on" responses in single neural units of central parts of the auditory neural pathways occurred when stimulus onset time was decreased. This finding implies that a greater rise-decay time effect would occur for briefer stimuli, since loudness judgments would be based on samples of neural information higher in "on" response synchrony over stimulus duration.

Condition 6 provides another estimate of the loudness of a 20-msec, 0-msec rise-decay time stimulus which is followed closely (5 msec) by

a second, 500-msec duration, 0-msec rise-decay time stimulus. This condition is identical to Condition 1 of Experiment III and the 70/70 condition of Experiment IV. All of the subjects in Experiment V had also participated in either Experiments III or IV. A comparison of equal loudness estimates across experiments (and methods) shows that these estimates were relatively consistent. For example, Subject mr set the physical intensity of the 20-msec signal at a value of 75.0 dB in Experiment V and 74.3 in Experiment III. Subject sr adjusted the signal to a level of 77.3 dB in Experiment V and 78.2 in Experiment IV. Subject kw, who participated in Experiments III, IV, and V, set signal levels at 66.0, 71.5, and 73.0 dB, respectively. Thus, at least two subjects were consistent within 1 dB across experiments.

A comparison of loudness estimates for Conditions 5 and 6 provides an initial look at the possible contribution of temporal proximity to signal loudness. These conditions, which differed only with respect to inter-stimulus interval, indicated that the signal more temporally proximal to the "interfering tone" was perceived to be less loud by almost 3 dB than the signal which was separated from the second stimulus by 500 msecs. This finding is potentially important with regard to Massaro's PAS model (1972a) which attributes decreases in pitch perception at short inter-stimulus intervals solely to reduced processing times.

Experiment V provided evidence which suggested that rise-decay time differences as small as 3 msecs can result in measureable, consistent differences in subjective intensity. The purpose of this experiment was to test the potential fruitfulness of future research in this area. It appears that such research is warranted.

## CHAPTER VI

### GENERAL DISCUSSION

The experiments described in the preceding chapters were designed to answer five fundamental questions regarding the perception of brief acoustical stimuli. The unifying theme of these somewhat diverse inquiries involved the relationship between pitch perception and physical and subjective stimulus intensities. Experiment I showed that changes in relative physical amplitude resulted in changes in the accuracy of pitch judgments, whereas Experiment II indicated that these pitch identification changes were, in fact, due to a varying relative amplitude and not simply to a changing physical amplitude. Experiments III and IV, in which the initial primary intent was to test an assumption underlying a popular pitch processing model (Massaro, 1972a), provided results suggesting that this equal loudness assumption was ill-founded, and furthermore, that accurate pitch perception was more highly correlated with subjective intensity than with physical intensity. The results of Experiment V suggested that subjective intensity (and therefore, perhaps, pitch perception) was influenced by a physical parameter of the stimulus that has, until now, received little attention. Because the results of individual experiments were discussed in some detail in their respective chapters, this discussion is limited to selected implications of the experiments as a group.

Regarding Massaro's (1972a) PAS model, the results of Experiments I-V strongly suggest that Massaro's notion of a sensory holding system

(i.e., PAS) may not be different from similar systems generated as the result of detection masking studies. Massaro (1972a) stated that "detection masking is a phenomenon that is closely tied to the psychophysical processes operating in simultaneous masking studies. Recognition masking, on the other hand, is closely tied to the temporal course of perceptual processing" (p. 130). To support this contention, Massaro pointed out that (1) the similarity of the frequency of the target stimulus to the masker is important in detection masking but not in the recognition masking process; (2) contralateral masking (target and masker are presented to opposite ears) does not occur in detection masking but does occur in recognition masking; (3) forward masking (masker precedes target) does occur in the detection masking studies, whereas it does not typically occur in recognition masking research; and (4) in detection masking studies the masking stimulus is generally louder than the target stimulus, thereby resulting in a decrease in the signal to noise ratio and not necessarily in an interference with pitch processing.

Research completed that is directly relevant to Massaro's PAS model cast doubt on the validity of some of the preceding points. First, the review presented in Chapter I indicated the importance of frequency similarity in recognition masking is equivocal. Secondly, Hawkins et al. (1974) showed that the contralateral masking effects reported in recognition masking could be eliminated simply by allowing the subjects to know beforehand in which ear the target would occur. Regarding the third point, the finding that an intense forward masker results in an increase in the threshold of a barely audible target (as in detection masking), but does not significantly interfere with the pitch perception

of an intense, suprathreshold signal (as in recognition masking) is not surprising. In fact, given the preceding findings regarding the enhanced loudness of the second of two temporally proximal stimuli, an increase in signal pitch perception might be expected. Finally, Massaro's assertion that the signal is equal in loudness to the interfering tone was disputed in Experiments III, IV, and V.

The resulting overall conclusion is that the procedure used to investigate the hypothetical, central cognitive-perceptual PAS system is of the same type as those used to examine more peripheral, psychophysical processes. Furthermore, there is no reason to believe that the PAS system is a functionally different operation, independent of psychophysical processes. Recent ancillary findings buttress this conclusion.

Yost and Thomas (Note 4) found that by incorporating an antiphase binaural signal (one ear is 180 degrees out of phase with the other) in the backward interference pitch recognition paradigm, pitch perception accuracy returned to a value that was not significantly different from the pitch perception of a signal presented without an interfering tone. The significance of this finding is that a similar situation exists in detection masking and is referred to as a "masking level difference." Massaro (Note 1) has stated that since the masking level difference phenomenon is associated with the detection process (which is independent of pitch processing), no improvement in pitch recognition would be expected with an antiphase signal. It is therefore the opinion of this investigator that the processes underlying signal detection are not discontinuous with the processes underlying signal dimension perception.

A similar conclusion was reached by Scharf (1971) who compared the findings of threshold and suprathreshold masking studies. Threshold (or detection) masking and suprathreshold (or partial) masking are defined as "the increase in the SPL of one sound required in the presence of a second sound to reach a criterion loudness level" (p. 31). Scharf presented evidence which indicated that "there is no discontinuity in the masking functions when the criterion level is raised from threshold to suprathreshold levels" (p. 30). An especially relevant point of this review is that the frequency similarity effects that occur in detection masking studies (and were cited by Massaro as being a critical difference between detection and recognition masking) tend to decrease with increases in signal intensity to such an extent that tones of all frequencies (between 600-2000 Hz) are masked to essentially the same degree by a narrow-band noise centered at 1000 Hz.

While the Scharf (1971) study investigated only one stimulus dimension, i.e., relative loudness, its pertinence to pitch perception is evident given the loudness-pitch perception relationship noted in Experiment IV. It should be pointed out that the studies cited in the Scharf review used broad- or narrow-band white noise as the masking stimulus and that the noise occurred simultaneously with the signal. For this reason, these results should be replicated using pure tones and a temporally discrete signal and masker.

It would also be interesting to discover what happens to the perceived loudness of a signal when it is preceded (forward masking) by a masking stimulus. An increase in perceived loudness would not at all be unexpected. Likewise, is the perceived loudness of the signal affected by signal channel specification under contralateral interference conditions?

Finally, does the subjective intensity of the signal increase with increases in the inter-stimulus interval? Studies of the preceding questions will contribute much to settling the question of whether the PAS is a unique, independent pitch processing construct or simply a point along the auditory processing continuum that differs quantitatively but not qualitatively from those points and processes typically termed "peripheral."

It was noted in Chapter I that the findings generated by the backward interference pitch recognition paradigm are relevant to several common auditory experiences. Among these experiences is the perception of consonant-vowel pairs in speech. In fact, an early investigator, Samoilova (1959), chose signal and interfering tone duration to correspond to the mean durations of the consonants (about 20 msec) and vowel sounds (about 300 msec) of speech. The results of the experiments in this paper may provide some ancillary information regarding the cues used in, for example, the perception of consonant-vowel pairs. While acoustical analyses of the spectra of consonant-vowel pairs have revealed that formant transitions (e.g., Harris, Hoffman, Liberman, Delattre, & Cooper, 1958), temporal gaps (e.g., Liberman, Harris, Eimas, Lisker, & Bastian, 1961), relative amplitudes (e.g., Heinz & Stevens, 1961), voice onset times (e.g., Eimas & Corbit, 1973), etc. can be important in the discrimination of consonant-vowel pairs, the results of the experiments described in this paper suggest that loudness differences resulting from differences in temporal gaps, voice onset times, and relative amplitudes may provide an additional cue in phoneme discrimination. An extensive discussion and test of this implication is beyond scope of the present paper and is left to future research.

Before concluding this discussion, a brief methodological note may be instructive. As noted in the Appendix, the theory of signal detection (TSD) allows the separation of individual response bias factors from the measures of stimulus sensitivity that are of interest. Which of the dependent variables of TSD, percent correct ( $P(C)$ ), areas under the receiver's operating characteristic curve ( $P(A)$ ), distance between the means of the noise and signal plus noise distributions ( $d'$ ), etc. is chosen depends upon the experimental situation. The measure,  $d'$ , used in Experiments I and II is appropriate when the underlying distributions of the signal and signal plus noise are assumed to be normal and of equal variance (a customary assumption in research of this type) and when a minimal response bias is expected (Green & Swets, 1966, p. 405). An analysis of the response preferences (independent of probability of stimulus occurrence) of the subjects in Experiment I and II using the sign test for large numbers (Siegel, 1956, p. 72) revealed no significant difference in "high" vs "low" pitch response tendencies.

A question concerning the use of  $d'$  as a dependent variable involves the determination of statistically significant condition differences. At present no formally stated test of statistical significance for  $d'$  values exists. However, because research that employs the  $d'$  as the dependent variable typically specifies a criterial variance (in the present case--5%) before data are tabulated, values of  $d'$  for other conditions that lie outside this range can be considered significantly different. Additional information regarding condition or individual differences can be gained from a comparison of the slopes of psychometric functions relating changes in  $d'$  as a function of varying stimulus values.

This general discussion of the implications of the overall results of Experiments I-V is not intended to be exhaustive and undoubtedly some minor implications have been omitted. Nevertheless, the preceding discussion does serve to illustrate the relevance of the present research to existing bodies of knowledge.

## APPENDIX

## APPENDIX

### SIGNAL DETECTION THEORY

The Theory of Signal Detectability (TSD) was chosen for use in Experiments I and II over more traditional psychophysical methods for a number of reasons. Not the least significant reason is the ability of TSD to separate measures of sensitivity from individual response biases.

TSD is based on statistical decision theory whereby a chosen response to a given event depends upon that event's value relative to some criterial probability of occurrence or ratio of probabilities (likelihood ratio). In a simple yes-no situation, values exceeding this criterion would be responded to as "yes," whereas values below this criterion would receive a "no" response. When a priori and a posteriori probabilities can be precisely stated, a likelihood ratio can be derived that will maximize correct responses. When dealing with sensory processes, however, the criterial value that results in a subject responding, "Yes, I did detect the presence of a signal" or "No, I did not detect the presence of a signal," for example, is largely a matter of the response proclivity of the subject (when the probabilities of occurrence for the two events are equal). For example, one subject may adopt a strict criterion which requires that the presence of the signal be very apparent before a "yes" response is registered. On the other hand, another subject may respond "yes" every time he imagines he detects the presence

of a signal. Most classical psychophysical methods could erroneously conclude that the sensitivity of these two subjects is different. TSD, however, allows these response biases to be removed from the final sensitivity estimate.

In a simple detection task, TSD assumes that when a signal occurs, the subjective experience of that signal is the sum of the signal presence plus the "noise" that is inherent in the sensory system. The value of the subjective experience of this signal plus noise is assumed to vary over time in a manner that can be described by some probability distribution. Unless otherwise determined, these overlapping noise and signal plus noise distributions are assumed to be normal and of equal variance. When an intense signal is presented, its probability of exceeding the background level of sensory system noise is high and detection is easy. When a sufficiently less intense signal is presented, however, its average level above the underlying noise is much less, and the probability that the experience of a signal's presence is due to a temporarily high noise level increases. For an identical physical signal intensity, two subjects with different levels of system noise would have different degrees of overlap of the noise and signal plus noise distributions. A convenient method for gauging signal sensitivity, then, would be to determine the degree of distribution overlap by deriving the distance between the means of the two distributions.

The estimate of this distance between means (or  $d'$ ) is determined by an examination of the responses that occurred at a given signal intensity. There are four types of responses that can occur on a given trial. First, a subject can respond "Yes, I detected a signal" on a trial where a signal was actually presented. This response situation is termed a

hit. On the other hand, a subject can respond "yes" when in actuality no signal was presented. This response is called a false alarm. Similarly, a "no" response when no signal was presented is termed a correct rejection, and a "no" response when a signal was presented is scored a miss. If a subject adopts a strict criterion to determine when he will respond "yes," he will commit few false alarms but will also have a lower number of hits (because he is responding "yes" less frequently). However, if he maintains a lax criterion, he will receive more hits, but will also score more false alarms. Because hits and false alarms co-vary with a changing response bias, the nature of overlapping normal distributions allows the calculation of a given  $d'$  value for various hit and false alarm rates. It is in this way that TSD arrives at a bias-free estimate of sensitivity.

The value of  $d'$  is standardized by subtracting the mean of the noise distribution from the mean of the signal plus noise distribution and dividing by the standard deviation of the noise distribution. Specific values of  $d'$  can be derived by calculating the hit and false alarm rates and entering an appropriate  $d'$  table. (The  $d'$  values of Experiments I and II were computed using the single-interval  $d'$  table in Swets (1964).) Hit rate is defined as the number of hits divided by the number of hits plus the number of misses for a given condition. Likewise, false alarm rate is calculated by dividing the number of false alarms by the number of false alarms plus the number of correct rejections.

As noted in Chapter VI,  $d'$  is appropriate when the noise and signal plus noise distributions are assumed to be normal and of equal variance and when subject response bias is not expected to be extreme.

If these conditions are not in evidence, another measure,  $P(C)$ , or per cent correct, is appropriate. The use of  $P(C)$  in Experiments I and II was simply to describe more clearly the three base levels of pitch discrimination performance and was calculated by dividing the sum of the hits and correct rejections by the total number of trials. The three base  $P(C)$ 's (multiplied by 100), 50-55%, 70-75%, and 90-95% correspond to mean  $d'$  values of approximately .10, 1.0, and 3.0, respectively.

A more detailed review of TSD can be found in Green and Swets (1966) and an introduction to some of the auditory processes with which this paper deals is contained in Yost and Nielsen (1977).

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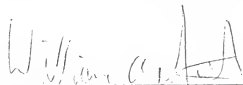
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Gerald Benjamin Thomas was born in Pottstown, Pennsylvania, where he attended parochial schools. When his family moved to Tampa, Florida, he enrolled in public school and graduated from Hillsborough High School. He received his B.A. in psychology from the University of South Florida and also earned his M.A. in experimental psychology in 1973 from the same institution. While completing his master's degree, he was awarded a University Council Fellowship.

His work experience has included serving as the chief faculty research associate with the Department of Criminal Justice at the University of South Florida and as a research and evaluation specialist with the Division of Children's Services for Hillsborough County. In September, 1974, he was accepted for advanced graduate study by the Department of Psychology at the University of Florida and was awarded a Graduate Council Fellowship. He has also worked as a graduate research assistant in the Institute for Advanced Study of the Communication Processes.

His major hobbies include virtually all sports, photography, and radios. He is married to the former Sherry Chastain and they have a Boston terrier, Duke Kahanamoku Thomas.

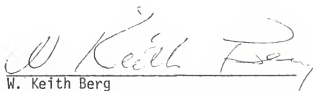
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